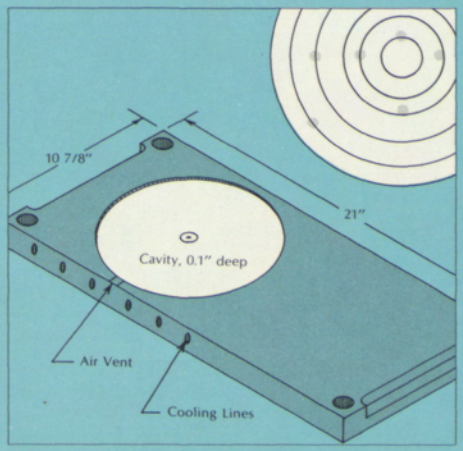
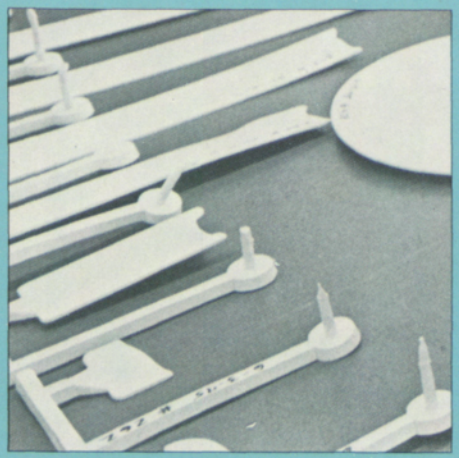
ENGINEERING

CORNELL QUARTERLY





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RESEARCH ASSOCIATED WITH INDUSTRY

Cornell's Injection Molding Project: Part of a New National Effort

by Kuo-King Wang

Until recently, research directly related to production problems in industry did not draw much interest in the universities. This is probably because the problems are often too practical to have any far-reaching effect on basic engineering disciplines; also, they are usually too complex to be attacked from a scientific viewpoint. Therefore, close association between universities and industry in production research has not been very common in this country.

However, since the establishment of the RANN (Research Applied for National Needs) program of the National Science Foundation, the situation has gradually changed in a few major universities. The deteriorating competitive position of the United States as compared to some other industrialized nations (Japan and Germany in particular) has drawn considerable attention in Congress as well as in the Administration, and in addition to promoting efforts in the areas of energy and environment, NSF/RANN is playing an important role in attacking the problems of industrial productivity. The Production Research and Industrial Automation Program of RANN has awarded major grants to several universities to support research that directly involves industry. Cornell's Injection Molding Project received one of these; others have been awarded to Stanford, Rochester, MIT, Case Western Reserve, Purdue, and several other universities.

WHY INJECTION MOLDING AND WHAT'S THE PROBLEM?

Injection molding is a manufacturing process for producing parts made of plastics, materials that have become increasingly important to our modern life. The volume of plastics being used today is actually greater than that of steels. And of the more than twenty billion pounds of plastics that have been produced annually in recent years, about one-third are molded.

The injection molding process, which shoots molten plastic into a mold under high pressure at high speed, has the inherent advantage of producing complex parts at low cost and to a tight tolerance. Plastics are no longer limited to cosmetic applications; they are a viable engineering material and possess superior properties. Precision gears accurate to a tolerance of $\pm$ 0.0005 inches are made by injection molding; the same process produces carburetors for small gasoline engines.

The injection molding industry is very fragmented, however. Mold design remains a matter of art, depending primarily on the designer's ingenuity and prior experience. Mold making, dominated by small shops, is characterized as labor-intensive and as such has faced formidable foreign competition. Industrial research and development effort has been concentrated on the improvement of the molding machine in its control and hydraulic systems through technology transfer from the machine tool industry, and sophisticated injection molding machines adaptively controlled by mini-computers have been developed. Yet little is known about what control algorithm ought to be used, since the material behavior in the mold is not well characterized.

Consequently, injection molding today can be a time-consuming and expensive process because of the difficulty of preparing the molds. For a critical part, months or even years of lead time may be needed for developing a successful production mold. The expense is considerable; for instance, an experimental mold for an automobile instrument panel could cost over a quarter of a million dollars.

THE PROJECT APPROACH: MANUFACTURING AS A SCIENCE

The main goal of our research project is to make effective use of the science of several engineering disciplines for advancing the state-of-the-art of injection molding. It is often said that manufacturing is not a science, but this interdisciplinary project is a serious attempt to apply fundamental principles to an important manufacturing process. Injection molding is treated as a system of mold design, mold making, and process control, each of which involves the use of computer techniques dealing with such problems as geometric part description, numerical simulation of fluid flow, and process optimization. Unlike basic research, the project work is not aimed at solving classical problems in rheology or fluid mechanics; rather, effort is concentrated on searching for approximate solutions that will produce useful results.

During the course of investigation, the project is expected to achieve the following specific objectives:

- Identify and solve rheological problems of prime importance to the analysis of injection molding.

- Develop numerical methods to simulate the injection molding processes of mold filling, packing, and solidification, and possibly the properties of molded parts.
- Develop experimental techniques to monitor the dynamic conditions of the polymer melt in the mold, and use these results to verify the simulation model.
- Establish quantitative guidelines for mold design, process control, and selection of equipment as a result of the numerical simulation. This information, in the form of tables and charts, is expected to have immediate use in the injection molding industry.
- Develop and implement an integrated computer-aided design and manufacturing (CAD/CAM) system to demonstrate the feasibility of automating the injection molding system for improving productivity.

Plastic parts made in injection molding experiments are examined by graduate student Alexandre Galskoy (left) and Professor Wang. These parts are "short shots" taken when the mold is still incompletely filled in order to examine the shape of the flow front.

Figure 1

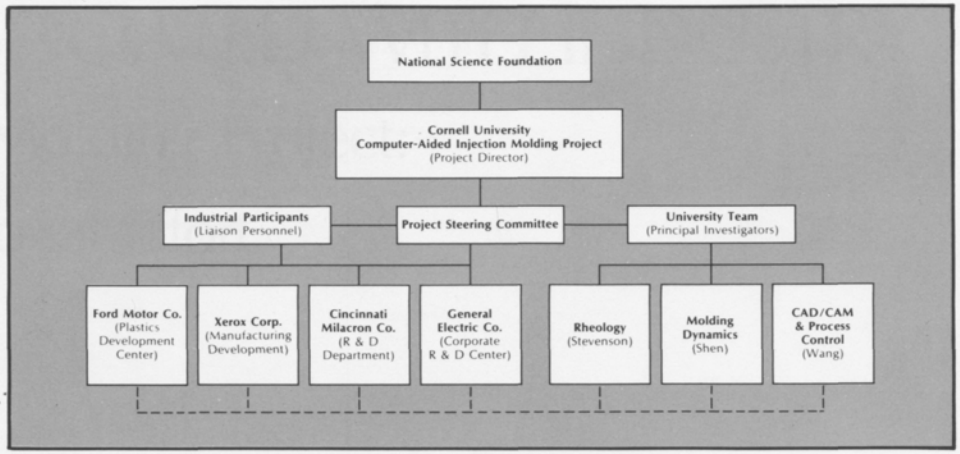
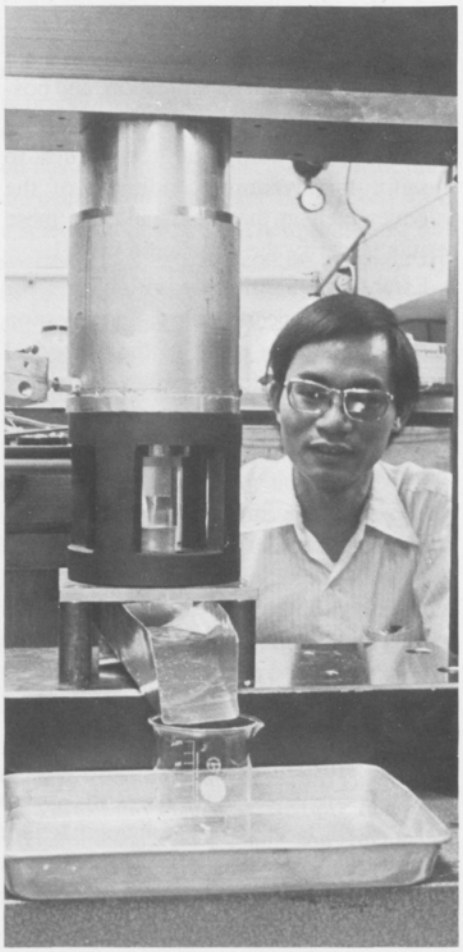


Figure 1. Organizational chart for the Injection Molding Project.

Below: Injection molding experiments with polymer solutions are performed by Simon Chung, Ph.D. candidate in chemical engineering, who studied the design of gates in injection molding as part of his doctoral research. For the Cornell project, he measures pressure drop across a gate with equipment especially designed and built at Cornell for these experiments.



THE UNIQUE FEATURE: COLLABORATION WITH INDUSTRY

The aspect of this project that distinguishes it from most other NSF-supported research is the direct involvement of industry. The idea of such involvement is to ensure cross-fertilization between theoretical knowledge and practical experience so that the research results will have impact on industrial needs in a relatively short term. In this spirit, major decisions are made by the Project Steering Committee, which consists of university investigators and representatives of industrial participants.

Figure 1 is an organization chart showing how the project is managed. The Cornell team consists of three groups of faculty members and graduate students working closely together. Professor James F. Stevenson of the School of Chemical Engineering heads the group that deals with rheology problems and provides information on material properties for flow analyses. The fluid mechanics group, led by Professor Shan-Fu Shen of the School of Mechanical and Aerospace Engineering, works on numerical simulation of mold filling, packing, and solidification processes. Computer programs developed by these groups are modulized and fitted into the main program developed by the design and manufacturing group, which also provides initial geometric data on the mold. The integrated program package will eventually generate control tape for machining the mold on a numerically controlled machine tool. The Cornell team has a total working force of twelve persons. In addition to three faculty members, it involves two postdoctoral research associates, Cornelius A. Hieber and John R. Ockendon (part time), and six graduate students (four M.S./Ph.D. and two M.Eng. candidates).

There are four companies participating in the project, each with a different industrial orientation and interest in the project. The Cincinnati Milacron Company, a major injection molding machine manufacturer, not only has developed the first computer-controlled molding machine, but also has substantial in-house R & D capability with regard to the process and rheology. In fact, most molding experiments of the project were performed at Cincinnati Milacron on their research machine equipped with an adaptive controller. The Ford Motor Com-

"The deteriorating competitive position of the United States as compared to some other industrialized nations . . . has drawn considerable attention in Congress as well as in the Administration"

pany, as a major user of plastic parts, is interested in automating the mold design and manufacturing process to cut down lead time and the cost of experimental molds. The Plastic Development Center at Ford Motor has extensive expertise in mold design and provides valuable advice to university investigators on practical considerations. The Xerox Corporation has interest in precision moldings that are characterized by high impact strength and dimensional stability. A recent participant is the General Electric Company; the corporate Research and Development Center of General Electric is concerned with new ways of improving the productivity of plastics processing, and as a polymeric materials producer as well as a major user, the company is interested in rheology and the process simulation aspects of the project.

Figure 2

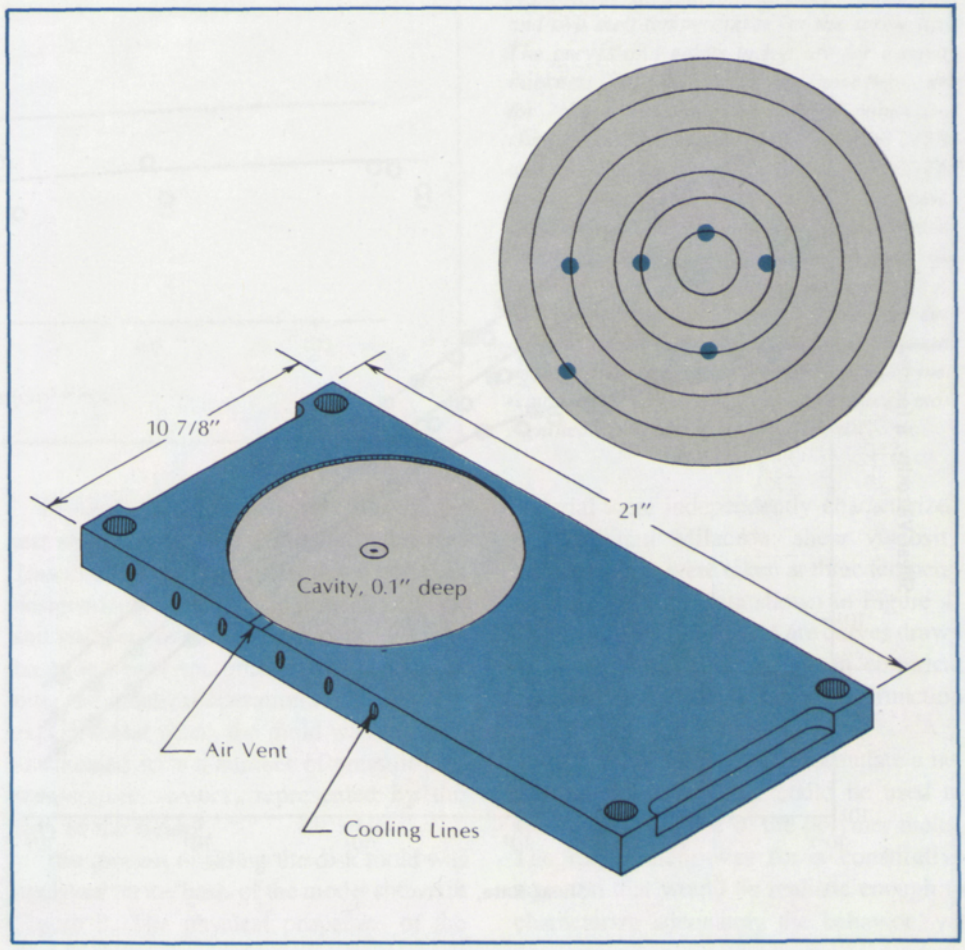


Figure 2. An isometric view of one of the project's test molds, a center-gated disk mold; and a schematic drawing showing the locations of pressure or temperature transducers. This mold was designed to be compatible with industrial use, and all measurements were performed under practical operations conditions.

Figure 3

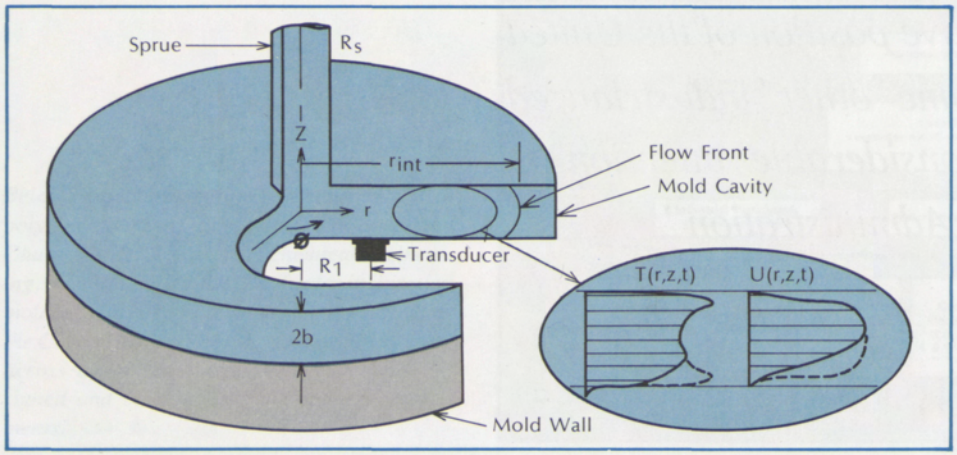


Figure 4

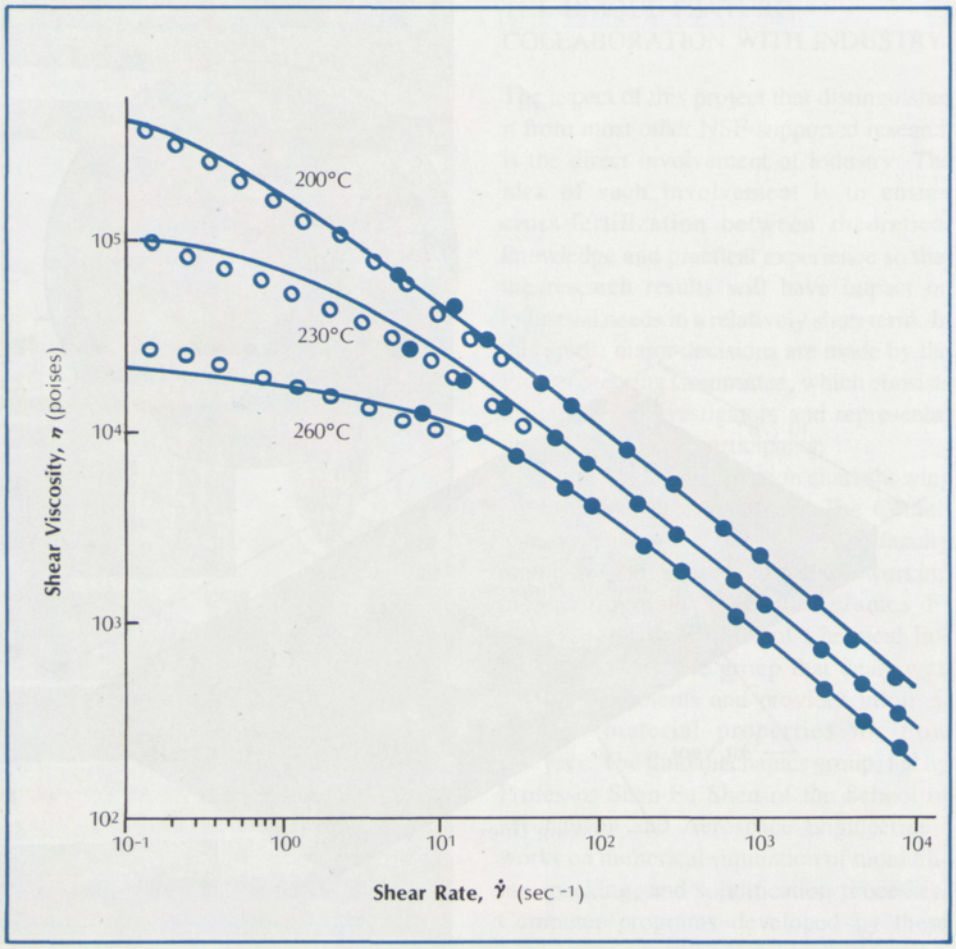


Figure 3. A schematic drawing of the model used to analyze the filling process for the mold illustrated in Figure 2. Also shown are enlarged views of typical symmetric (with respect to z) and asymmetric temperature and velocity profiles, $T(r,z,t)$ and $U(r,z,t)$, pertaining to the flow in the cavity of thickness 2b. The material used in the experiments is Lustron ABS Q 714, made by the Monsanto Company.

Figure 4. Experimental measurements of shear viscosity of the plastic material used in the work referred to in Figures 2 and 3. Open symbols denote cone-and-plate data obtained with a Rheometrics mechanical spectrometer; solid symbols denote data obtained with an Instron capillary rheometer (Rabinowitsch corrected).

The curves are drawn according to the empirical equation for shear viscosity: $\eta = \eta_0/[1 + (\dot{\lambda}\ \gamma)^{1-n}$, where the zero-shear-rate viscosity $\eta_0 = B \exp(\Delta E/RT)$, the time constant $\lambda = A\eta_0$, and $\dot{\gamma}$ is the shear rate. $B, \Delta E, A, R$, and n are constants and T is the absolute temperature. It may be noted that at high shear rates, the equation can be simplified to a power-law expression for shear viscosity: $\eta = N\dot{\gamma}^{n-1}$, as evidenced by the straight-line portion of the curves.

Cornell investigators usually keep close contact with their respective counterparts in participating companies. For instance, upon request of our rheology group, Drs. I. Jen Chen and Dean H. Reber, experimental rheologists at Cincinnati Milacron, characterized material properties using their well-equipped laboratory facilities. Frank A. Pink of Ford and William J. Mueller of Xerox have contributed their expertise for the design of test molds from the practical viewpoint. Dr. Larry Schmidt of General Electric has provided the results and experiences of his study of injection molding.

Figure 5

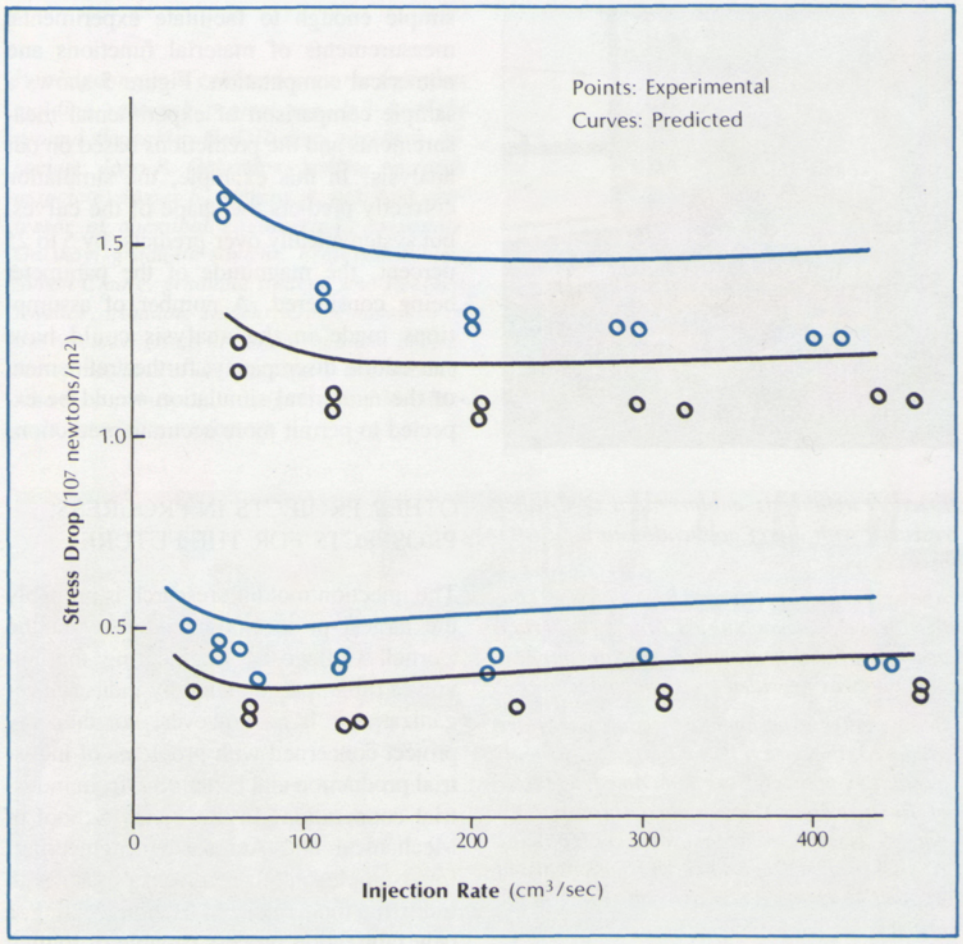


Figure 5. Comparisons of experimental (points) and predicted (curves) values for the pressure drop as a function of injection rate for four experimental conditions. The pressure drop was measured at the radial position R_1 in Figure 3.

The measurements were made with a pressure transducer at point R_1 for various values of injection rate and for two cavity thicknesses and two melt temperatures (at the screw tip). The curves and points at top are for a cavity thickness (2b) of 0.254 cm, and those below are for 2b = 0.406 cm. The colored points and curves represent measurements taken at 243°C and those in black correspond to 265°C. The predictions were made, with fluid time-dependence and normal stresses neglected, according to a generalized Newtonian model relating stress and strain-rate tensors.

The discrepancies between measured data and the simulations are owing to assumptions made in the analysis. Neglecting the inlet melt temperature profile probably contributed most significantly to the over-prediction.

ANALYSES AND EXPERIMENTS UNDER PRACTICAL CONDITIONS

Flow analysis and molding experiments are essential parts of the project, and numerical methods are developed for predicting the flow behavior of polymer melts in the mold. Most previous work has treated the problem under idealized conditions such as isothermal filling and low flow-rate, but to meet the objective of our project, our experiments were all carried out on an industrial injection molding machine under practical conditions.

Figure 2 shows a schematic of one of our test molds, one with a simple geometry. This center-gated, circular-disk mold was designed according to industrial practice and made out of an industrial standard mold base, and our experiments were performed over the practical operation range. For the experimental work, the mold was fully instrumented with a number of pressure and temperature sensors, represented by the dots in the figure.

The process of filling the disk mold was analyzed on the basis of the model shown in Figure 3. The physical properties of the material were independently characterized at Cincinnati Milacron; shear viscosity measurements were taken at three temperatures to yield the data shown in Figure 4. The solid lines in Figure 4 are curves drawn to fit the data according to an empirical equation for the shear viscosity as a function of the shear-rate.

Part of our work was to formulate a numerical simulation that could be used to predict the behavior of the polymer melts. The requirement was for a constitutive equation that would be realistic enough to characterize adequately the behavior, yet

Friction welding is another area of Cornell research with direct application to industrial production.

Above: Technician Richard Boyce operates the friction welding machine in Cornell's materials processing laboratory. The experimental machine was provided by the manufacturer.

Below: After experimental friction welds are prepared, they are tested for strength with ultrasonic equipment. Here Sami Amed, a Master of Engineering (Mechanical) degree candidate, tests welds in the laboratory of Wolfgang H. Sachse of the Department of Theoretical and Applied Mechanics, who is cooperating in the project.

"These projects represent a new kind of interaction among industry, government, and university."

simple enough to facilitate experimental measurements of material functions and numerical computation. Figure 5 shows a sample comparison of experimental measurements and the predictions based on our analysis. In this example, the simulation correctly predicts the shape of the curves, but systematically over-predicts, by 5 to 25 percent, the magnitude of the parameter being considered. A number of assumptions made in the analysis could have caused the discrepancy; further refinement of the numerical simulation would be expected to permit more accurate prediction.

OTHER PROJECTS IN PROGRESS; PROSPECTS FOR THE FUTURE

The injection molding research is probably the largest project now underway at the Cornell College of Engineering that involves direct participation by industrial organizations. It is, however, not the only project concerned with problems of industrial production and benefitting from industrial cooperation. In the Sibley School of Mechanical and Aerospace Engineering, for example, another current project with industrial input is one in friction welding, a new fabrication process capable of joining dissimilar metals with high joint efficiency. This work includes investigation of bond mechanism, weldability, and nondestructive testing. The Caterpillar Tractor Company, the manufacturer of the welding machine, has donated an experimental machine for our laboratory, and funding has been provided by the Eastman Kodak Company and the Welding Research Council.

These projects represent a new kind of interaction among industry, government, and university. Companies have always had a natural interest in engineering education as a source of technical or managerial per-

Participating in a conference on the injection molding research project are, left to right around the table: Neil Hieber, research associate; John R. Ockendon, visiting research associate; James F. Stevenson, assistant professor of chemical engineering; Alexandre Galskoy, graduate student; Professor Wang; Simon Chung, graduate student; and Praveen Khullar, graduate student. Other members of the research group are Shan-Fu Shen, professor of mechanical and aerospace engineering, who is co-principal investigator, and M. Morjaria, graduate student.

sonnel, as well as of fundamental research ultimately necessary for technology advancement. Engineering schools have always had a substantial interest in industrial organizations as the chief executors of American technology and employers of engineering graduates. Government, at least in recent years, has been the chief source of financial support for basic research programs, which are carried out largely in universities. However, cooperative efforts in supporting and conducting scientific research on specific industrial production problems have been relatively rare. The Cornell Injection Molding Project may be one of the first of a growing number of industry-associated research efforts in the nation's universities.

Kuo-King Wang, associate professor of mechanical engineering, already had acquired an unusual combination of industrial and academic experience before he joined the Cornell faculty in 1970.

He received his undergraduate education in China and worked for shipbuilding corporations in Shanghai and Taiwan before coming to the United States in 1960. After a year as superintendent of a liquid-sulfur carrier project for the United Tanker Corporation of New York, he studied at the University of Wisconsin for the M.S. degree in mechanical engineering, granted in 1962. For the next four years he worked as a project engineer in the process development engineering department of the Walker Manufacturing Company in Racine. He completed graduate studies at Wisconsin, earning the Ph.D. in 1968, and served as assistant professor there for two years before coming to Cornell.

At the present time Wang is a consultant to Therm, Inc., of Ithaca, New York, and to IU Energy Systems, Inc., of Philadelphia. Previously he served as a consultant to several Wisconsin firms: the Allis-Chalmers Manufacturing Company, the Walker Manufacturing Company, and Research Products, Inc. He has also been a consultant for the RANN Program of the National Science Foundation, and the Maritime Administration.

He is a member of the American Society of Mechanical Engineers and in 1968 received the ASME Blackall Machine Tool and Gage Award for the best paper in the field published by the Society. He is a member also of the American Society for Metals, the Society of Manufacturing Engineers, and the Numerical Control Society.

BEYOND THE CAMPUS

Engineering Education and the "Real World"

by Richard H. Lance

The interaction that takes place between the engineering college and the "real world" is a catalyst in the complex reaction that results in useful citizens, productive engineers, and new knowledge.

Industry needs engineers to carry out its functions in the conception, development, manufacture, and marketing of goods and services, and since industrial organizations depend on engineering schools to produce graduates with timely and vital preparation, they have a strong interest in those institutions' educational and research programs. On the other hand, engineering schools depend strongly on industry for intellectual and financial support. Interaction between technical education and industry has developed as a result of mutual needs and benefits.

At Cornell our concern is to maintain a curriculum and research base which reflects modern science, technology, and engineering practice. The importance of industrial interaction in achieving this end is indicated by the variety and extent of our industrial contacts. Some of the interaction programs provide support for the College in a financial or programmatic sense, and serve to help the faculty relate its interests to the concerns of a technological society: the Engineering Consortium, the continuing education program, and the activities of the Office of Special Projects are examples. Certain programs are directly concerned with individual students: Engineering Expo, Project VIEW, the Engineering Cooperative Program, and Master of Engineering project work, for example. Other programs that help students acquire and apply their education include corporate financial aid, the job placement program, and on-campus conferences for special groups.

Some of these programs have been in operation for many years and some have been developed quite recently in response to changing conditions and emerging needs. The importance the College administration places on an active and responsive program of industrial interaction is indicated by the fact that it has set up an Office of Industrial Liaison and named an associate dean to administer it. In this capacity, I will review the various cooperative programs of the College, with the aim of bringing about a clearer recognition of their usefulness and of stimulating the development of new interaction with industry, business, and government.

INDUSTRIAL INFLUENCE IN ENGINEERING EDUCATION

Several of the interaction programs carried on by the College involve activities which are virtually invisible in the educational processes that directly involve students, but which nevertheless may have an effect on educational programs through their influence on the faculty and administration. Among activities of this kind are the programs of the Engineering Consortium, the continuing education program, and research-associated interactions.

The Engineering Consortium is an association of the College and a group of member corporations that participate in a program of mutually beneficial interaction. The Consortium was created about six years ago to provide a formal mechanism for communication and action on educational and related concerns. It was recognized, for example, that the significant amount of sponsored research at the College is of interest to people in industry who can benefit directly from it.

Member companies have direct ties with the College in a number of ways. Members are entitled to enroll employees in short

MEMBERS OF THE CORNELL ENGINEERING CONSORTIUM

Eastman Kodak Company

E. I. DuPont de Nemours and Company

General Motors Corporation Rochester Products Division

The Gleason Works

Hughes Aircraft Company

International Business Machines Corporation

Mobil Research and Development Corporation

Olin Corporation

Phelps Dodge Corporation

Raytheon Company

Xerox Corporation

Zurn Industries, Inc.

courses offered by the College during the summer, or in videotape courses. They may participate in the Engineering Cooperative Program with special fee privileges. Special workshops and placement programs for company representatives are arranged by the College. Member companies also have the privilege of drawing on College faculty and staff expertise, and making use of the library facilities. On-campus visits are encouraged, and group consultations with faculty members can be arranged.

EXTENDING THE EDUCATIONAL PROCESS TO GRADUATES

The College offers a variety of continuing education programs for engineers and scientists in industry, research, private practice, government, and education.

A program of long standing is the summer short-course series attended by practicing engineers and educators representing both public and private organizations. Each of these one- or two-week courses is a concentrated, noncredit study of a subject or skill essential to an understanding of some area of modern engineering or technology. Courses given in 1975, for example, were in the fields of structural analysis, wastewater treatment, electron microscopy, and library processing.

VIDEOTAPED COURSES FOR OFF-CAMPUS INSTRUCTION

Recent installation of television equipment and control apparatus in two classrooms at the College has made possible a new program of off-campus courses that use videotapes of regular on-campus classes and lectures. Master of Engineering degree candidates at remote locations can earn credit by means of this system, or the courses can be taken on a noncredit basis. Arrangements are made between corporations, who enroll their employees in the program, and the College. Since 1973, when the program was inaugurated, fifty students at three industrial sites have been enrolled in fourteen graduate courses.

Videotaped undergraduate courses in the College's core engineering sciences have recently been made available for lease to industrial organizations and educational institutions. So far four community colleges in New York State have used the basic electrical science-circuits course to supplement their engineering science offerings.

FUNDING FOR RESEARCH Cornell College of Engineering 1974-75	
Source of Grants	Expenditures
Federal Government	$6,333,000
Industry	351,000
Other	59,000
Total	$6,743,000

INTERACTION WITH INDUSTRY THROUGH RESEARCH ACTIVITIES

Noninstructional activities, usually associated with research programs, are an important area of interaction between the College and industry.

A forum for regular communication on recent research in the various specialty fields and on technological developments is provided by the weekly seminars and colloquia sponsored by all the academic departments and schools. Speakers include Cornell professors and students, visitors from other institutions, and scientists and engineers from industry; and industrial representatives are encouraged to attend and participate in these sessions. These seminars and colloquia are an essential part of the academic program. Their usefulness to industrial organizations is being enlarged through a new service that will make videotaped recordings available to Engineering Consortium members and others. Under the plan, videotape cassettes of on-campus lectures can be delivered to remote sites for viewing at the convenience of the audiences.

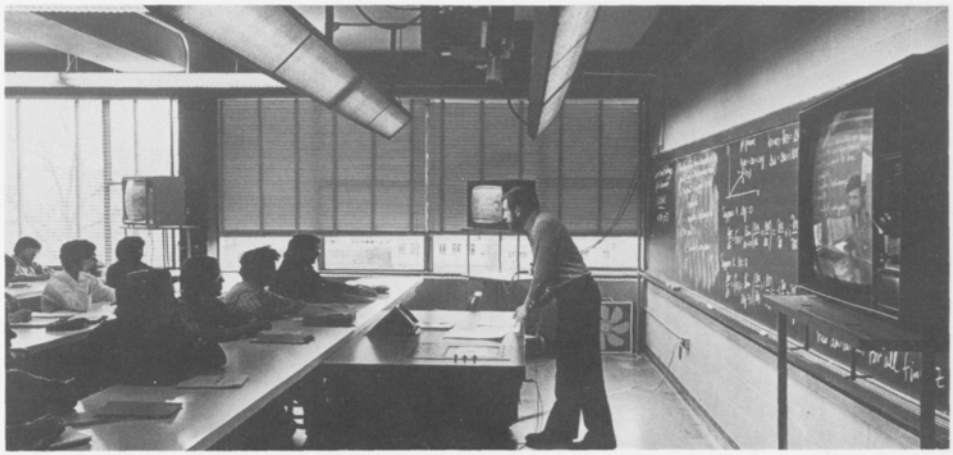
A major form of interaction is industrial consultation by members of the College faculty. Consulting offers advantages to the company, which benefits from the expertise of the faculty member, and to the professor, who keeps in touch with what is going on in the field. It is important that our faculty be involved with real problems in order to be able to educate engineers effectively.

"It is important that our faculty be involved with real problems."

COLLEGE INITIATIVE IN ARRANGING SPECIAL PROJECTS

In addition to continuing programs of interaction, special projects are frequently undertaken. Sometimes these take the form of sponsored research or support for educational programs. Sometimes one or more industrial organizations provide funding for facilities or programs which they perceive as contributing to the long-term interests of their areas of operation. Occasionally a program of cooperative research or development is implemented.

An example of a special project is the recent installation and equipping of a clean-room facility for crystal growth and semiconductor processing at the School of Electrical Engineering, which was financed by contributions of a number of industrial firms. Another example is the



Regular course lectures are videotaped in specially equipped classrooms on campus for use in classes conducted at industrial locations. Employees are enrolled by cooperating corporations; examinations are administered at the plants and evaluated by the professor. Here Professor Lance conducts a class in advanced engineering analysis.

Above: A 24-channel truck-mounted seismic system, a gift of the Shell Oil Company, is being used by the Department of Geological Sciences for seismic studies. The explosion of dynamite generates shock waves which result in the reception of seismic data from several miles below the earth's surface. Industrial cooperation is also important in the Department's largest current research project, a study of the deep continental basement by means of seismic reflection profiling.

Right: A clean-room facility for crystal growth and semiconductor processing at the School of Electrical Engineering was funded by a number of industrial firms. A major contributor was the International Business Machines Corporation.

Department of Geological Sciences' deep reflection seismology profiling project, which has received corporate help in the form of data acquisition and consultation, as well as National Science Foundation funding.

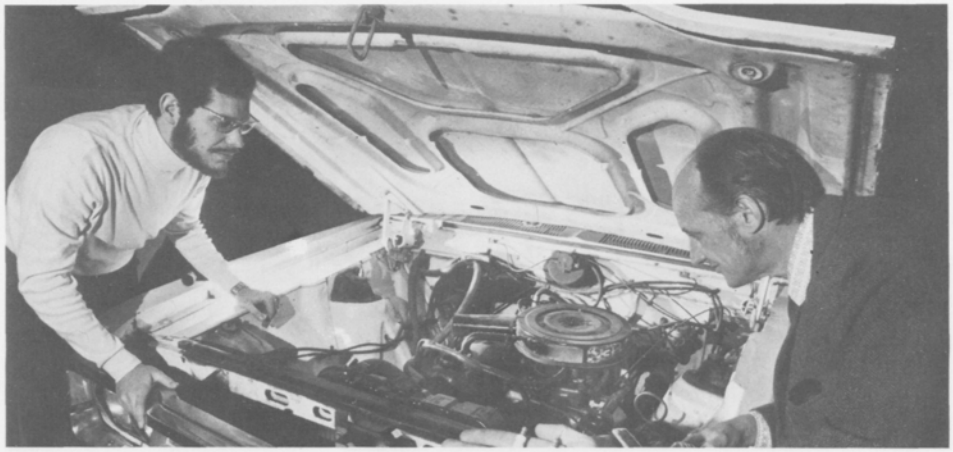
Help in seeking support is provided by the College's director of special projects, Donald F. Berth, who works closely with the University development officers. The director serves as an intermediary in facilitating arrangements for new ventures conceived by industrial representatives or College personnel.

INDUSTRIAL EXPERIENCE FOR STUDENTS AT CORNELL

The principal "product" in the industry of education is the engineering graduate. In many cases, exposure to the roles of engineers in actual job situations has helped engineering students set goals, discover role models, and relate their academic progress to future professional work. In fact, this aspect of the overall educational process is especially valuable at a school like Cornell, which is situated in a predominantly rural environment with limited "built in" access to industrial activity.

An automobile emission control system developed by Cornell researchers with industrial cooperation, recently passed official tests and meets the pollution control standards set for 1977. Herbert Kosstrin (left), a research associate, and Edwin L. Resler, Jr. (right), the Joseph Newton Pew Jr. Professor of Engineering and director of the Sibley School of Mechanical and Aerospace Engineering, developed the system, which consists of slight modifications of spark plugs, pistons, and manifold (see the Winter 1974 issue of this magazine for a description of the early development of the nitrogen oxide control system). According to Resler, the modifications can reduce pollutants without compromising performance or gasoline mileage and could be implemented inexpensively, with only slight retooling, by automobile manufacturers. Cornell University, which holds the patent rights, is planning to license use of the system and its component parts.

The two vehicles used in the project are owned by the Southern New England and the New York Telephone Companies, which cooperated in the research and will road test the cars. Representatives of AT&T and of Bell Telephone Laboratories also cooperated. Pollution measuring equipment was purchased with a grant from the Bell Laboratories.



The oldest and most significant of several professional exposure programs at the College is the Engineering Cooperative Program, which provides Cornell engineering students the opportunity to obtain industrial experience while still in college. The students in the program spend alternate periods on campus and in industry during their upperclass years, and obtain almost a year of paid professional experience without extending the date of graduation. The experience in the field contributes to their personal and professional growth and helps them relate their academic studies to engineering practice. The advantages of the program to the participating organizations include the opportunity to take part in the educational direction of future engineers. Also, the program can be of help to the organization in its efforts to recruit permanent employees.

Thirty-eight companies and corporations participate, and a total of 117 students—110 men and seven women—are currently enrolled in the program. Its director is Robert N. Allen, associate professor of operations research and industrial engineering. The program was initiated almost thirty years ago.

THE NEW PROJECT VIEW FOR WOMEN AND MINORITY STUDENTS

A newer and very important program, which addresses the problem of motivation for students who are women or members of minority groups, is Project VIEW (Vantage: Industry and Engineers at Work). This program was initiated five years ago in response to a group of our minority engineering students who expressed an interest in observing firsthand the role of the engineer in contemporary industry. In the first year of the program, one-week assignments at five companies were arranged during the winter recess for a dozen minority sophomores. Because of the enthusiastic response of both students and companies, the program has been expanded so that this year sixty five sophomores and twenty companies participated.

The main purpose of VIEW is to reinforce the technical and professional interests of students from groups that historically have been underrepresented in engineering education, and to promote a sense of professional identity and direction. The program helps compensate for the scarcity of professional "role models" for women and for members of minority groups by providing for a period of close contact with practicing engineers from these groups. A secondary purpose is to help the students choose a field for upperclass study: exposure to the engineer's world of work can be particularly helpful to those who are still unsure of their technical interests. The program gives organizations the opportunity to extend their educational outreach efforts and also to establish contact with students who offer potential for summer and permanent professional employment.

The program is directed by David C.

Johnson, assistant dean and director of student personnel, with the assistance of Mary D. Ott, research associate in the Division of Basic Studies, and Eugene J. Wilson, director of engineering minority programs.

AN INDUSTRIAL EXPOSURE PROGRAM FOR UNDERCLASSMEN

A broader program, called Engineering Expo, was initiated recently to help all underclass students understand the profession of engineering. During their first two years at the College, students have not yet chosen their engineering majors, and they frequently ask many questions about the profession and their own professional development. These questions are directed to peers, parents, faculty advisers, and professors, for usually the students do not have access to the persons most qualified to answer: engineers currently practicing in the field. Engineering Expo is an attempt to utilize this important resource for advising our students.

The format is simple. Interested students are asked to sign up for an on-site visit to a nearby engineering firm that is participating in the program. During the visit they are given a tour of the facilities and briefed on the various functional areas of engineering, such as sales, production, and research and development. Firms are encouraged to arrange programs that reflect the nature and organization of their enterprise, with the result that no two trips are alike in either style or content. Most of them, however, include individual conferences between students and engineers. Each year about fifteen firms and one hundred fifty students participate in the program, which was initiated and is arranged through the College's Advising and Counseling Center, under the direction of Robert E. Gardner.

A group of underclassmen visited the Endicott, New York plant of the International Business Machines Corporation last spring as part of the College's Engineering Expo program.
Above: Company representatives demonstrate a high-speed check sorter, which can increase the interest earnings of large banks by as much as $1 million a year by speeding up the processing of incoming checks. Robert E. Gardner, College adviser, is second from right.
Right: The check-sorting process is explained by Craig Sherer, senior associate engineer. The students also attended presentations on manufacturing and development and toured the bioengineering laboratory.

On-campus interviews between employers and engineering students facilitate job placement. About 130 companies regularly send representatives to the College during sessions held in the spring and in the fall. Here Roger Baker, recruitment representative of the Shell Oil Company, interviews a prospective employee.

INDUSTRIAL PARTICIPATION IN M.ENG. PROJECT WORK

At the heart of the curriculum leading to the one-year Master of Engineering degree—the first professional degree granted by the College of Engineering—is the design project. Each M.Eng. student is required to complete an individual or group project involving significant design effort and chosen to represent the kind of problem encountered in actual practice.

This is an aspect of engineering education that obviously benefits from the participation of industrial firms through their professional staffs. Practicing engineers are encouraged to become involved as deeply as practicable in the selection of design problems and in the strategies of solution, solution development, and evaluation. For the students, the experience enhances professional development and helps build a strong base for sound engineering judgment. Advantages to the industrial participants include the opportunity to contribute to the educational process and to develop contacts with potential employees.

At the present time the most active program of industrial participation in M.Eng. project work is in civil and environmental engineering (see the photo-essay on page 22). During the period between academic semesters, the Department of Structural Engineering and the Department of Environmental Engineering each provide intensive, three-week group design project sessions under the supervision of faculty members and industrial or consulting engineers. The project work is prepared for in planning sessions during the fall term, and is completed by the preparation and presentation of a detailed report. There is interest at the College in extending this kind of program to other disciplines.

COOPERATIVE EFFORTS IN JOB PLACEMENT

Activities that affect the students' academic and professional lives but bear little or no direct relation to the academic programs constitute another area in which industrial organizations simultaneously contribute to the College program and derive benefits from contact with future engineers. Placement activities and career information services are examples.

The major functions of Cornell's Engineering Placement Office are to assist degree candidates in identifying career goals and to help them find associated opportunities with those industries, firms, and governmental agencies that typically recruit at Cornell. This office is closely coordinated with the University's Career Center, which serves as the clearinghouse for career information, graduate school opportunities, and requests from industrial organizations for recruiting. Any engineering student may call upon either office for information, career counseling, or appointments for personal interviews with representatives of prospective employers. Most placement interviewing for engineering students is conducted at the College. About 130 companies send representatives.

Because of the competitiveness of the job market at the present time, the College's Engineering Placement Office is making special efforts to expand the placement services for students and companies. For example, the usual spring cycle of placement interviews has been augmented by a fall cycle, since many firms begin looking for promising applicants early in the academic year. In addition, a series of workshops for students on effective techniques in writing application letters,

". . . although engineering is increasing rapidly in both scope and complexity, it retains its basic alignment with technology."

preparing resumes, and interviewing, were introduced this year. The first two sessions were conducted by John Munschauer, director of the University Career Center, and the third one was conducted by William Neely of Corning Glass Works.

STUDENT FINANCIAL AID FROM CORPORATE SOURCES

As a private institution, the College of Engineering at Cornell has always faced the challenge of providing sufficient student aid resources to ensure a diversified and well qualified student body. In recent years, as educational costs have risen sharply, the problem of providing adequate support has become more acute. In the 1974-75 academic year, over half the College's approximately twenty-two hundred undergraduate egineering students required financial aid. Cornell sources provided scholarships worth more than two million dollars to these students.

Industrial firms have had a share in providing support for the student financial aid programs at the College. Examples of current corporate contributions are the Alcoa Foundation Scholarships for upperclass students in five designated engineering fields; the Scott Paper Company Leadership Award Program, which is designed to recognize primarily academic and personal achievement; and the Rohm & Haas scholarship funds for students in chemical engineering. Ten companies have contributed funds for the support of minority programs, including financial aid for students. Unfortunately, the economic retrenchment of the last few years has forced many companies to reduce or discontinue their scholarship support programs. The need continues, however, and with greater urgency. The College believes that industry must and will reevaluate its position in this important area, recognizing the critical need of engineering schools for assistance in their efforts to maintain quality programs and student enrollments.

ON-CAMPUS CONFERENCE FOR SPECIAL STUDENT GROUPS

Conferences for current and prospective woman and minority students have been held at the College of Engineering for the past few years, and have proved effective both in encouraging the enrollment of students from these groups and in helping them choose and prepare for specific careers. These conferences have been arranged by the College's Office of Student Personnel and the Engineering Advising and Counseling Center, or by student organizations with the cooperation of these offices, and they have had support from industrial sources.

An example is the conference for prospective and enrolled women that is sponsored annually by the Cornell section of the Society of Women Engineers. The 1975 program, "The Woman Engineer: Student and Professional," was attended by nearly one hundred applicants to the College and practically all of the current female undergraduate and graduate students. The three-day conference included class visits, meetings with engineering faculty and staff members, panel discussions with experienced women engineers and corporate placement officers, and a plant visit. Later in the year a national conference on "Women in Engineering — Beyond Recruitment" attracted about eighty delegates from universities and industrial organizations to the Cornell campus.

Programs for representatives of minority groups include a series of weekend campus visits arranged by the Office of Student Personnel for groups of twenty prospective

A check for the Alcoa Foundation Scholarships is presented to Dean Edmund T. Cranch by representatives of the Aluminum Company of America during a visit to the campus. Left to right are David R. Balok from the Alcoa plant in Massena, New York; Dean Lance; Dean Cranch; and George W. Anderson, also from Alcoa in Massena.

undergraduates. Another example of such programs is a career conference for minority engineering and business students that was held on campus in the spring of 1975 under the sponsorship of the Black Electrical Engineers, a student organization.

The contributions of industrial organizations, both financially and in the form of program participation by company representatives, has been crucial to the success of these conferences. Among the sponsors have been the Bell Telephone Laboratories, the Corning Glass Works, E. I. DuPont de Nemours and Company, the General Motors Corporation, the Martin-Marietta Aerospace Corporation, the Mitre Corporation, and the Stone and Webster Engineering Corporation.

TECHNOLOGY—BASIC TO ENGINEERING EDUCATION

Of all the areas of higher education, engineering is the one most closely associated with industrial activity. And although engineering is increasing rapidly in both scope and complexity, it retains its basic alignment with technology. The education of engineers—in the classroom, the research laboratory, and the work place—and the results of university research are legitimate concerns of industry; likewise, the needs and directions of industry figure importantly in the programs of vital and effective engineering educational institutions.

Because contact is essential in promoting these mutually supportive relations, the Cornell College of Engineering continues to seek innovative programs with industry.

Richard H. Lance assumed responsibility for liaison between the College of Engineering and industry when he was appointed to a new associate deanship in 1974. As discussed in this article, his office coordinates the various programs at the College that involve outreach beyond the campus. An associate professor of theoretical and applied mechanics, he maintains a research program in addition to his administrative activities.

Lance has been a member of the Cornell faculty since 1962. He served as acting chairman of the Department of Theoretical and Applied Mechanics in 1973-74, served several terms as Graduate Field Representative, and has been a member of the Graduate Programs Committee, which supervises the professional Master of Engineering degree program. He also served on a special committee to study the use of video techniques in engineering education, and he was active in establishing and teaching in the College's instructional television program. In University affairs, he has been an elected member of the University Senate and is now on the Faculty Council of Representatives and serves as a member of the Committee on Academic Programs and Policies. Several summers ago he was a leader of a New Orientation Program Wilderness trip for incoming freshmen.

He earned the B.S. degree in mechanical engineering from the University of Illinois in 1954; the M.S., also in mechanical engineering, from the Illinois Institute of Technology in 1957; and the Ph.D. in engineering mechanics from Brown University in 1962. After completing his undergraduate education, he worked as a test engineer for the Minneapolis-Honeywell Regulator Company, and before beginning doctoral studies, as a mechanical engineer with the Ingersoll Milling Machine Company.

He is a member of the American Society of Mechanical Engineers, the American Association for the Advancement of Science, the Society of Engineering Science, and Sigma Xi.

BEYOND THE CAMPUS

The "Outside" Professional Activities of Cornell Engineering Professors

When the sabbatic leave comes along every seven years, two out of every four Cornell engineering professors go to another university in this country or abroad, one goes to work in a governmental laboratory or agency, and one spends the leave in industry.

Further connection between the College and industry is achieved through the continuing consulting activities that a large majority of the faculty maintains.

These are among the conclusions drawn from the results of a recent survey taken by the College's Office of Industrial Liaison (see Figures 1 and 2). The data suggest the balance between fundamental and applied research that exists at the College, originating with the faculty and reflected in the academic programs. While the preponderant amount of funded research is supported by governmental grants, and characteristically has a basic scientific emphasis, most of it has at least potential applicability, and there is a significant amount of industrially sponsored research as well (see the Table on page 12).

INCREASED EFFECTIVENESS THROUGH SABBATIC LEAVES

Tenured professors are granted paid leaves from the University with the expectation that the special experiences they are able to acquire will increase their effectiveness in their academic roles.

In the recent College survey, 130 professors—most of those who have had leaves—provided information on their latest two sabbatics. In some cases the leave was divided, with part of the time spent at a university, for example, and part with an industrial organization; these were counted in both categories.

Most of the respondents spent their leaves conducting research in laboratories elsewhere, where they had access to unique facilities, where they could work closely with other specialists in their field of expertise, or where their special knowledge could

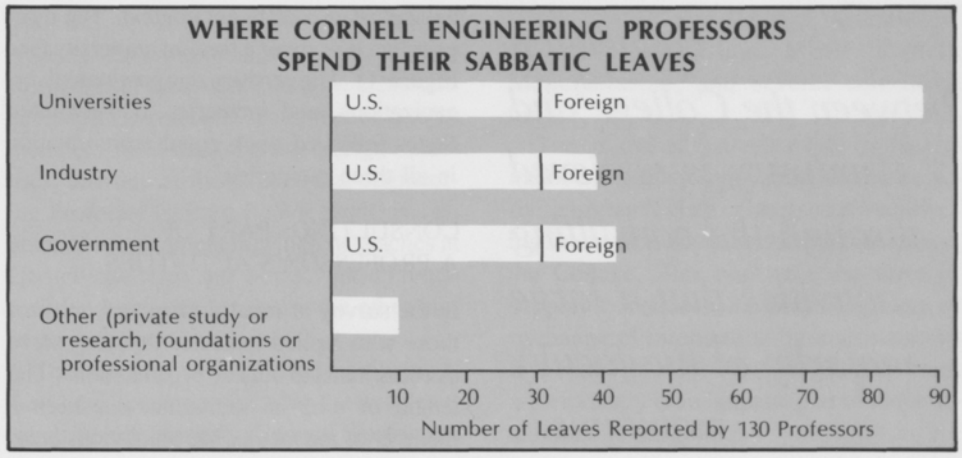


Figure 1. Although the greatest number of Cornell engineering professors spend their leaves in research and teaching at other universities, leaves spent with industrial organizations are a significant fraction of the sabbatic activities.

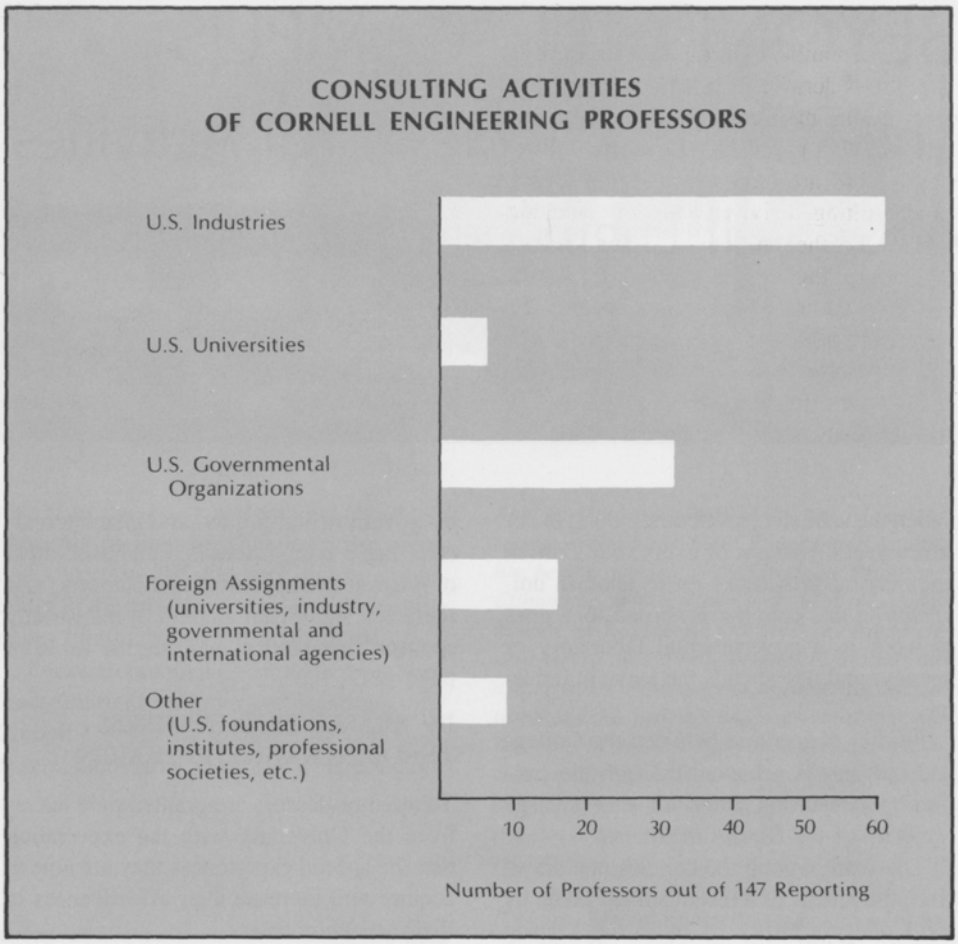


Figure 2. Most Cornell engineering professors serve as consultants to outside organizations, especially industrial firms. Each of the professors represented in the total count for a given category may be a consultant to a number of organizations of that type.

". . . connection between the College and industry is achieved through the consulting activities that a large majority of the faculty maintains."

be applied in a different context. The most popular choice was a foreign university (see Figure 1). Universities, governmental organizations, and industries in the United States followed, with equal representation in all three categories.

CONSULTING: PART OF A PROFESSOR'S ACTIVITIES

In the survey of faculty members, most of those who replied indicated that they serve as consultants to outside organizations. The length of time an individual has been a member of the faculty has an obvious bearing on the extent of the involvement: many of the younger faculty members have not yet established consulting arrangements. But most of the tenured faculty (associate and full professors) serve as consultants,

often for a number of organizations, or have done considerable consulting at various times during their careers.

Of the 218 members of the engineering faculty, 147 are represented in the survey on consulting activity, and these include almost all of the senior faculty. The kinds of consulting they do are summarized in Figure 2; the total for each category is the number of professors who reported one or more consulting assignments of that type.

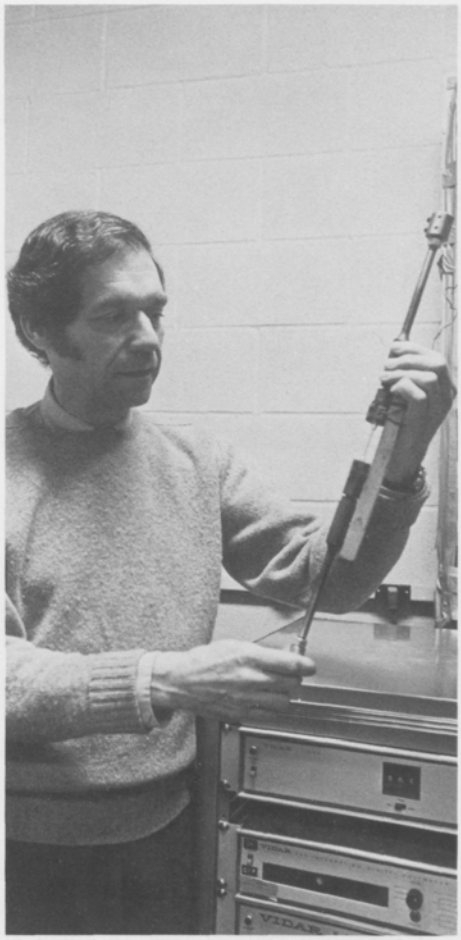
Industries that have consulting connections with the College of Engineering represent all the disciplines, and include manufacturing firms, data processing companies, research and development divisions, and consulting firms. Several textbook publishers call on professors for review opinions, and some consulting is done with private individuals such as attorneys. In the public sector, faculty consultants work with agencies at the national, state, and local levels, in such areas as energy and power supply and development, environmental protection, and sanitary engineering.

Related activities with industrial organizations include summer employment in research, consultation, or teaching, and participation in off-campus seminar and course work during the academic year. There is some cooperative research in progress; the project discussed elsewhere in this issue by Professor Kuo-King Wang is an example, and research that Professor Dieter G. Ast has conducted for the past several years in conjunction with people from Westinghouse, Xerox, and IBM is another.

Some of the College's professors extend their consultation to foreign or international operations, and many of these involve industry. Professors Donald J. Belcher and Ta Liang, for example, have worked with a number of companies all over the world on resources development and public works projects. Professor Daniel P. Loucks has worked with the World Bank in economic development research. A number of faculty members are consultants for foreign industries, and one of them, chemical engineering Professor Herbert F. Wiegandt, has an unusual arrangement in which he teaches at Cornell one term and works with a French petroleum refining company the other half of each year.

Industrial firms with which faculty members have spent leaves during the past seven years include, notably, General Electric and IBM. Others are Cayuga Associates, Eastman Kodak, Ford Motor, Powers Manufacturing, and several consulting firms.

The industrial contacts made by faculty members through consulting and leave activities often initiate or help sustain continuing interaction between the companies and the College. This may take the form of support for research, cooperative efforts, or exchange of information through seminars and visits. In all these ways, faculty work with industry is an intrinsic part of the overall College program.



The pattern of university professors spending leaves in industry is occasionally reversed, with researchers from industrial firms spending leaves on campus. At Cornell this year as a visiting professor is Edward W. Hart, a physicist with the General Electric Company Corporate Research and Development Center in Schenectady, New York. Hart and the General Electric Center have been closely associated with experimental programs at the College since 1971. The collaboration began with the research group headed by Professor Che-Yu Li of the Department of Materials Science and Engineering, and involved not only Hart, but four postdoctoral associates from the company. The interaction was extended to the Department of Theoretical and Applied Mechanics in 1974. This year Hart, a University of California (Berkeley) Ph.D. in theoretical physics, is teaching and conducting theoretical and experimental research in both departments. The work, on the deformation behavior of metals, is described by Hart as "basic, but with fairly immediate potential for application."

Professionals Serve as M.Eng. Design Consultants

Four practicing engineers working with teams of College graduate students are helping to make this year's Master of Engineering (Civil) design projects timely and pertinent to current professional practice. The consultants are from firms that are doing or have recently completed designs for the same projects, and therefore they have valuable background information on the problems and experience in dealing with them.

As a result of these arrangements, the contact with "real world" engineering is at a very high level, according to Professor Richard N. White, who is in charge of the professional degree program for his school.

The plan for design work in this program is to organize the students into groups of up to fifteen members for the comprehensive design of an actual engineering installation. Each group begins work in the fall under the supervision of Cornell faculty members, and concludes the year's project in the spring with a full written report and an oral presentation. A high point of activity is a three-week session between academic terms, when the students work full-time on their projects. The industrial consultants come to the campus during this period, and usually during the early and late parts of the fall term and for the presentation.

One of the three industry-related projects this year is titled, "Design of Bridge Across Piscataqua River." Richard Christie, a partner of Hardesty & Hanover, a New York City consulting firm specializing in bridge design, is the professional consultant to the thirty students (in two groups) who are involved in the design work. John F. Abel and Robert G. Sexsmith are the professors in charge.

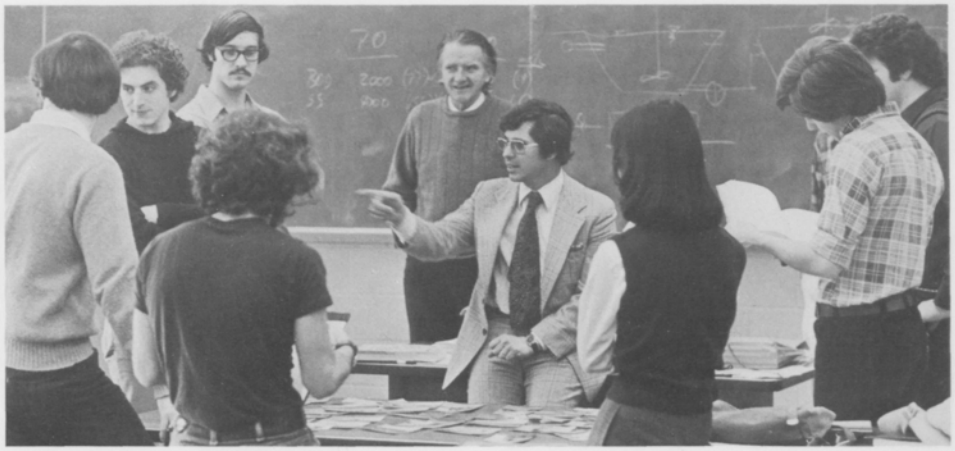
A group of fifteen students is working on "A Liquefied Natural Gas Terminal at Cove Point, Chesapeake Bay, Maryland," under the direction of Professor J. Neil Kay and consultant Melvin Esrig of the soils engineering firm of Woodward Clyde in Clifton, New Jersey.

"Development of an Economical Waste Water Treatment Plant for the Doe Run Effluent, Olin Chemicals Group, Brandenburg, Kentucky" is a project involving fourteen students working with Professor Vaughn C. Behn and with H. H. Hogeman, D. R. Vaughn, and C. Thomas Avery of the Olin Chemicals Group. Paul Busch of Malcolm Pirnie and Associates, White Plains, New York, is also a consultant.

This is the fourth year in which this kind of design program has been in effect in civil and environmental engineering. In that time, eleven group projects, all with professionals as consultants, have been undertaken. Projects in addition to the current ones include designs for a cable-stayed bridge, a hangar and maintenance facility for an airport, and portions of an offshore floating nuclear power station. Environmental and sanitary engineering students participated in design work for a radioactive waste treatment system for an offshore generating station, automated and computer-controlled municipal wastewater treatment systems, a water treatment plant, and the upgrading of a sewage treatment plant.

Right above: Existing facilities at the Olin Corporations's Doe Run Works, for which Professor Behn's group of graduate students is designing a new waste water treatment plant, include a sludge control house, a sludge thickener (the structures at center), and a spill basin (foreground).

Right below: The existing aeration basin appears in the foreground, with the neutralization basin beyond.



Above: Paul Busch (center) of Malcolm Pirnie Associates was on campus during the three-week intensive design period to consult with the student group designing a waste water treatment plant for Olin's Doe Run facility. Professor Behn, the faculty adviser, is at center behind Busch.

Below: Busch confers with student team members, including Gary Lorgan (at upper left), the student coordinator. The design provides for an expanded facility that will enable the Doe Run plant to meet proposed, more stringent discharge standards. The plant produces a variety of derivatives from propylene and ethylene oxide; wastes are biologically treated in the activated sludge facility.

1

1. Consultant Melvin Esrig (at right center) confers with M.Eng. students during the winter intersession design period. This group is working on the design of a liquefied natural gas terminal. Professor Kay, the faculty adviser, is at left center.

2. Students worked in small teams on specific aspects of the overall design.

3. Students working on a tied-arch design for a cable-stayed bridge over the Piscataqua River between Portsmouth, New Hampshire and Kittery, Maine include (left to right) William Haner, Tim Kirby, and Anthony Aguero.

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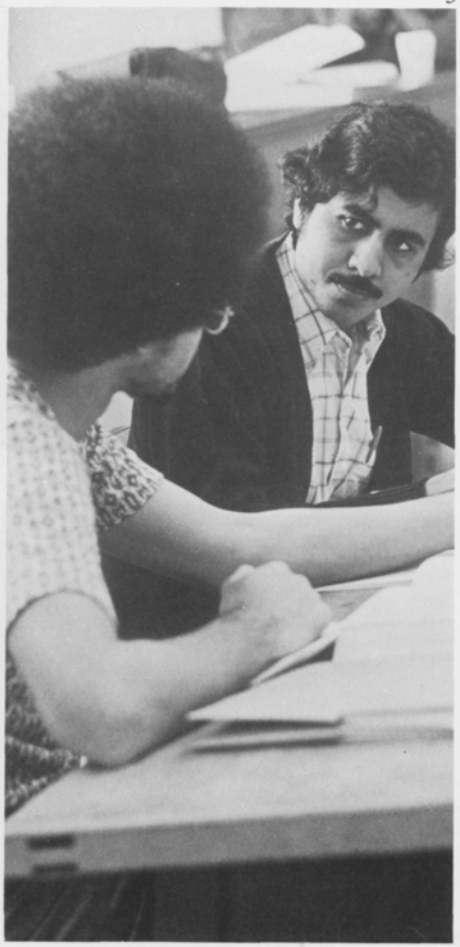

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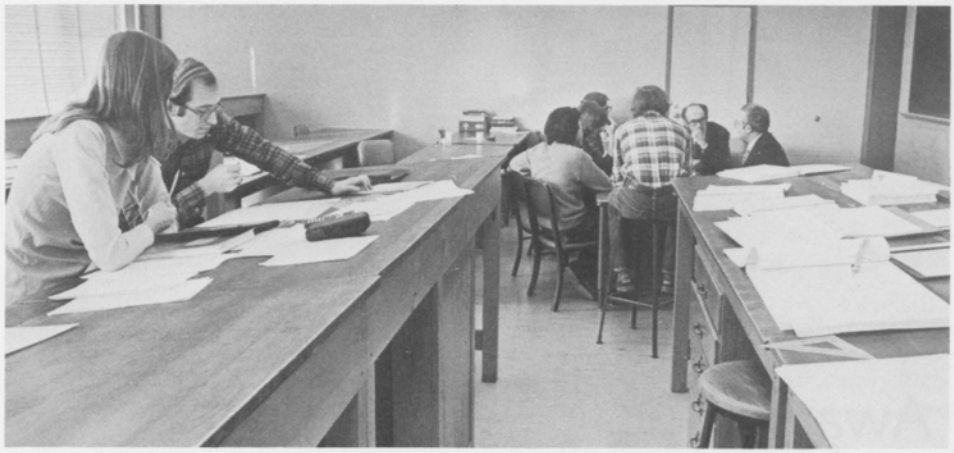

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4. Richard Christie, a partner of Hardesty & Hanover, confers with students on the bridge design. Left to right in foreground are Louis Pesquera, Paul Dionisio, Christie, and John Hart (one of the group leaders).

5. Students Paul Clarke (left) and Mushtaq Ahmed are responsible for the design of approach spans for the bridge.

6. Professor Abel discusses lateral bracing for the tied arch design. This was one of two alternative designs taken to final stages.

7. The actual bridge was recently constructed according to the design prepared by Christie's consulting firm, Hardesty & Hanover.

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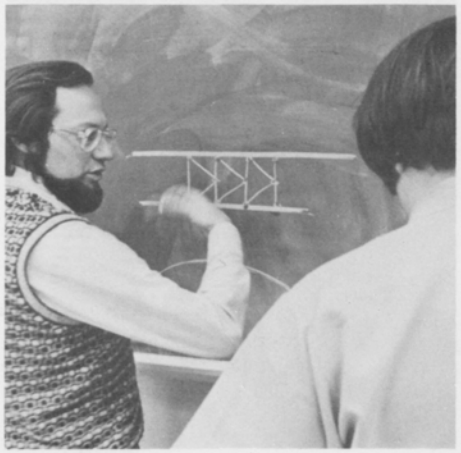

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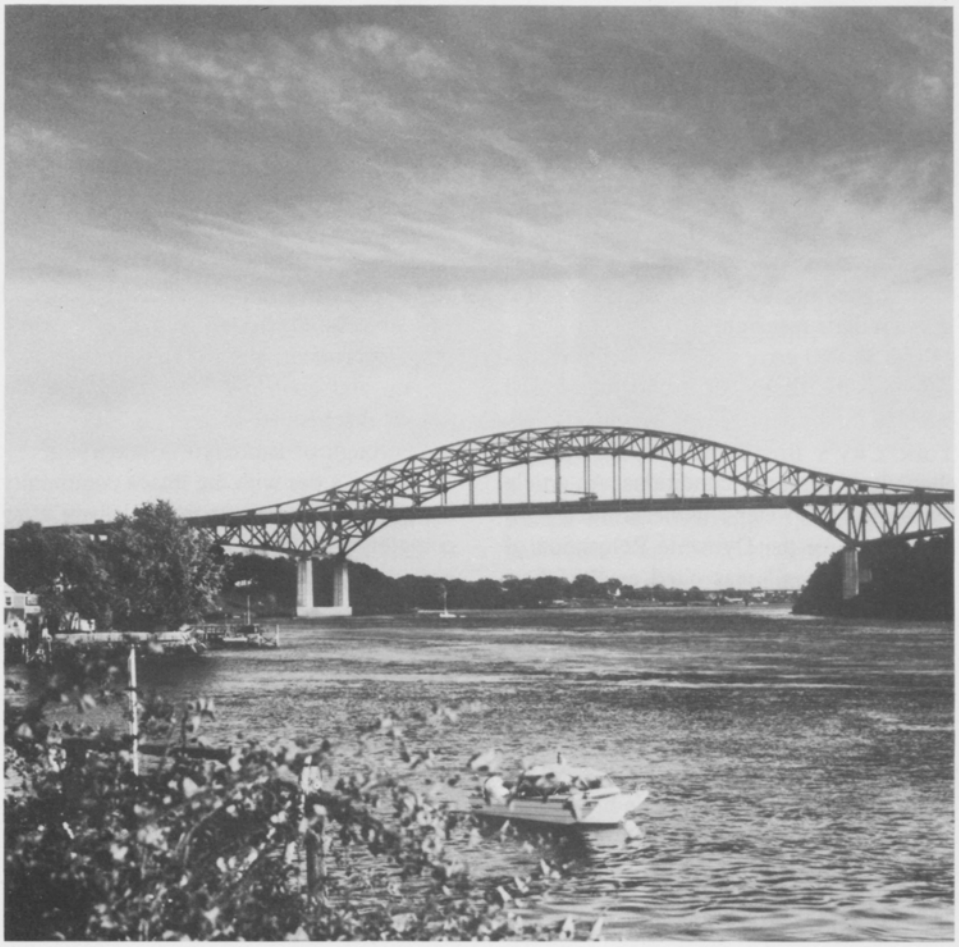


Engineering Honors Awarded

■A Cornell engineering doctoral graduate was one of two Rand Corporation researchers who received the coveted Lanchester Prize from the Council of the Operations Research Society of America (ORSA) this fall. He is Warren E. Walker, who earned three degrees from Cornell: the B.A. in mathematics in 1963, the M.S. in operations research in 1964, and the Ph.D., also in operations research, in 1968.

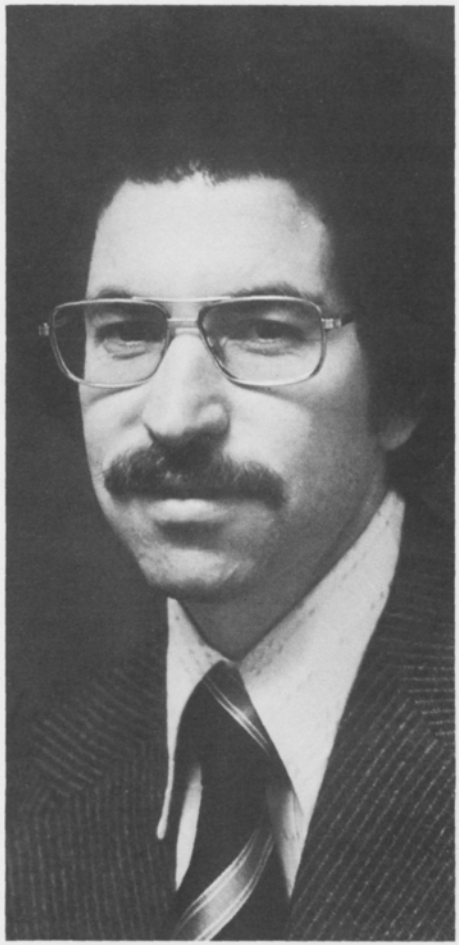
The $2,000 prize was awarded in recognition of the design of a computer-based method for prompt redeployment of New York City's fire companies in rapidly changing emergency conditions. An article by Walker and Peter J. Kolesar titled "An Algorithm for the Dynamic Relocation of Fire Companies" was cited as "the best English-language published contribution to operations research" in 1974. It was prepared in the course of studies for New York's fire department by the New York City-Rand Institute, and was published in *Operations Research,* the journal of ORSA.

The prize was presented in mid-November just two weeks after the Institute was closed as a result of New York's financial difficulties. Both Kolesar, now a Columbia University professor, and Walker, now an assistant vice president of the Chemical Bank of New York, remain as consultants to the parent Rand Corporation, which is completing unfinished work of the Institute. At the Chemical Bank, Walker is engaged in branch location research and long-range planning.

The system the prize-winners designed was successfully tested by the New York Fire Department, and a management information and control system based on the design is scheduled to go into operation in the borough of Brooklyn in late 1976.

Walker's ties with the Ithaca community include two years with a local firm; after completing his Cornell studies, he served as president and treasurer of Compuvisor, Inc., his own computer development firm.

He first became associated with Rand in



Right: Warren E. Walker, former Cornell graduate student in operations research, won the Lanchester Prize of the Operations Research Society of America for his work on a computerized system for emergency redeployment of New York City fire companies.

Below: Mr. and Mrs. Joseph Silbert, at center, were photographed with Dean and Mrs. Edmund T. Cranch at the award dinner. Right: The silver medal was presented by Cornell President Dale R. Corson.

1966, when he participated in the corporation's Graduate Student Summer Program. After receiving his doctorate, he served for two years as a consultant to the Fire Project of the New York City-Rand Institute, and then joined the Institute full-time. In addition to his fire department studies, Walker also worked on the Institute's Police Project, which included the development of a simulation model of patrol activities and study of other problems associated with the allocation of police resources, the scheduling of patrol cars, and manpower scheduling.

He also directed a related project, supported by the Department of Housing and Urban Development (HUD), on the deployment of municipal emergency systems. This work is designed to test, document, and disseminate to cities throughout the country systematic methods for analyzing emergency service deployment problems. The methods have been field tested in eight cities.

Walker has also taught at Columbia University and the New School, and served as a consultant to the Solid Waste Management Office of the federal Environmental Protection Agency.

■ A recent recipient of the College's highest honor, the Engineering Award, is Joseph Silbert, Buffalo industrialist who established an endowment for the Joseph Silbert Deanship of Engineering in 1973.

A silver medal, representative of the Award and inscribed "in appreciation of his support of the College," was presented to Silbert at a special dinner during the fall meeting of the Engineering College Council by Dale R. Corson, former dean of the College and now president of the University. Host at the dinner was Edmund T. Cranch, current dean and first holder of the Joseph Silbert deanship. Speaking on behalf of the Council was chairman Arthur M. Bueche, vice president of the General Electric Company.

Mr. Silbert founded the American Allsafe Company, Inc., and was a pioneer in industrial safety engineering. He received the A.B. degree from Cornell in 1915.

The endowment of the deanship, the first of its kind at Cornell, provides salary and related support for the dean in his administrative capacity at the College and for educational activity at the state and national levels.

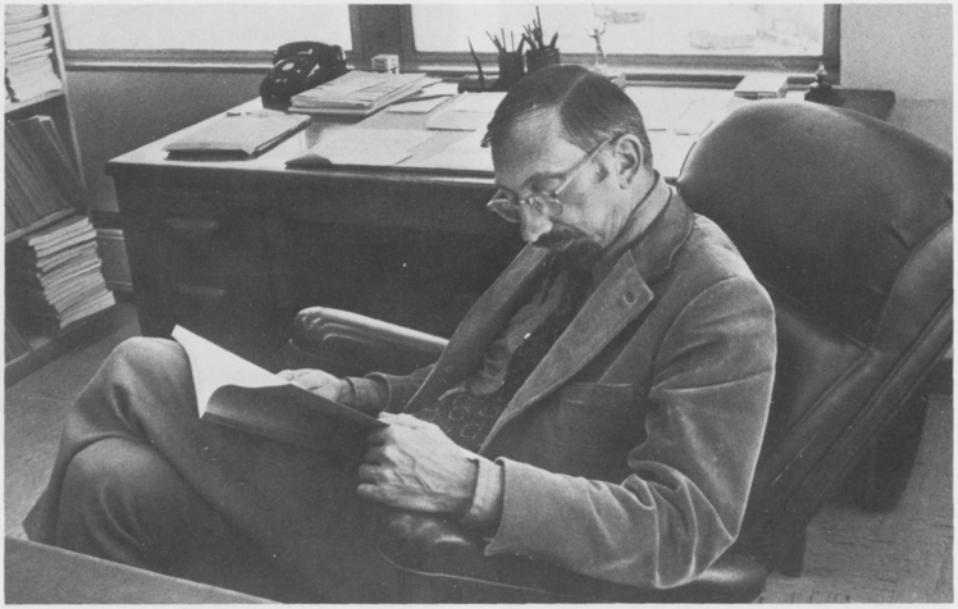
Professor of Operations Research Dies

■ The College of Engineering and the School of Operations Research and Industrial Engineering lost a distinguished faculty member with the death on January 10 of D. Ray Fulkerson, the Maxwell M. Upson Professor of Engineering, at the age of fifty-one.

He is survived by two sons, his mother, and four sisters and brothers.

Fulkerson, a specialist in network flow theory, combinatorial analysis, and linear programming, joined the University faculty in 1971 after twenty years with the Rand Corporation. He was a 1947 graduate of Southern Illinois University, which honored him in 1972 with the Alumni Award for outstanding professional achievement. He held M.S. and Ph.D. degrees in mathematics from the University of Wisconsin.

Fulkerson had published more than sixty papers in professional journals and was coauthor, with L. R. Ford, Jr., of *Flows in Networks,* published in 1962 by Princeton University. In 1967 he received one of the annual Ford Awards of the Mathematical Association of America, which are given in recognition of outstanding articles. He was on the editorial boards of five professional journals.



We have lost a warm and close friend whose integrity, compassion, and modesty endeared him to students and colleagues alike. The scientific community has lost an outstanding scholar and one of its foremost research workers in network theory and combinatorial analysis. He was one of the pioneering giants in the field of operations research, and throughout the history of the profession he has been at its forefront. His fundamental contributions will continue to have a major and lasting impact on the field.

—Robert E. Bechhofer, Director
School of Operations Research
and Industrial Engineering

FACULTY PUBLICATIONS

The following publications and conference papers by faculty members and graduate students of the Cornell College of Engineering were published or presented during the period May through July 1975. Earlier publications inadvertently omitted from previous listings are included here with the date in parentheses. The names of Cornell personnel are in italics.

AGRICULTURAL ENGINEERING

Black, R. D. 1975. *Flood proofing rural residences: A "Project Agnes" report.* U.S. Dept. of Commerce, Economic Development Administration.

Hussain, A. A. M.; *Rehkugler, G. E.;* and *Gunkel, W. W.* (1974). Tree limb response to periodic discontinuous sinusoidal displacement. *Transactions of the American Society of Agricultural Engineers* 18:614–617.

Jewell, W. J.; Davis, H. R.; Johndrew, O. F., Jr.; Loehr, R. C.; Siderewicz, W.; and *Zall, R. R.* 1975. *Egg breaking and processing waste control and treatment.* U.S. Environmental Protection Agency report no. EPA-660/2/75-019. Corvallis, Oregon: National Environmental Research Center, Office of Research and Development.

Scott, N. R. 1975. Radio Telemetry. Chapter 12 in *Instrumentation and measurement for environmental sciences,* ed. Z. A. Henry. St. Joseph, Michigan: American Society of Agricultural Engineers.

Srivastava, A. K., and *Rehkugler, G. E.* 1975. Strain Rate Effects in Similitude Modelling of Plastic Deformation of Structures Subject to Transient Loading. Paper read at Annual Meeting of American Society of Agricultural Engineers, 22–25 June 1975, at the University of California, Davis.

APPLIED AND ENGINEERING PHYSICS

Baidyaroy, S.; Clark, M. D.; and *Ballantyne, J. M.* (1975). Barrier configuration for efficient tunnel-injection of minority carriers. *American Physical Society Bulletin* II20:556, paper AL6.

Ballantyne, J. M.; Clark, M. D.; and Baidyaroy, S. (1975). Electroluminescent metal-insulator-semiconductor devices. *American Physical Society Bulletin* II20:556, paper AL5.

Clark, M. D.; Baidyaroy, S.; and *Ballantyne, J. M.* (1975). Electron tunneling through evaporated aluminum oxide films. *American Physical Society Bulletin* II20:556, paper AL4.

Elson, E. L., and *Webb, W. W.* 1975. Concentration correlation spectroscopy: A new biophysical probe based on occupation number fluctuations. Chapter in *Annual review of biophysics and bioengineering,* vol. 4, pp. 311–334. El Camino, California: Annual Reviews.

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