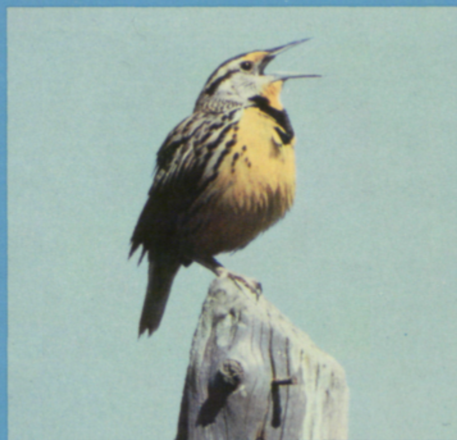
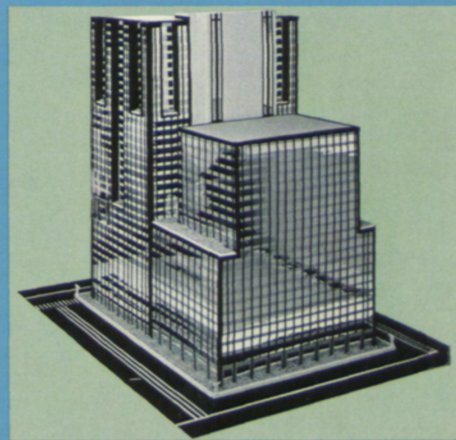
ENGINEERING

CORNELL QUARTERLY





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PROJECTS AND PROSPECTS FOR M.ENG. STUDENTS

IN THIS ISSUE

2

8

10

19

23

26

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Cover : Illustrations from M.Eng. project work (clockwise from noon): the Eastern meadowlark, one of the birds whose song can be shifted down to a more audible frequency (page 21); the model of a building designed by student teams (page 23); part of an elephant-call sonogram (page 21); the geometry of a "wrinked" flame as revealed by a laser technique (page 11).

Opposite: African elephants studied in the field for research on animal sounds (page 19).

EDUCATING MASTERS OF THE ENGINEERING PROFESSION

by K. Bingham Cady

For a student who wants a good start on a career as an engineer—rather than as a researcher, professor, physician, lawyer, or some other kind of practitioner—Cornell's Master of Engineering program fits the bill.

The M.Eng. is a *professional* degree. Planned as the fifth year of engineering education, it adds focus and specialized instruction at the graduate level to the B.S. curriculum, which emphasizes basic preparation in science, mathematics, and engineering fundamentals. Many B.S. graduates develop careers as practicing engineers, but those who go on for the fifth-year M.Eng. have a decided advantage in both expertise and salary.

This is hardly a well kept secret. The M.Eng. at Cornell has shown the most growth of any of the engineering programs (see Figure 1), which means that students and employers appreciate its value. We now graduate almost half as many Masters of Engineering as Bachelors of Science. The M.Eng. attracts more than twice as many students as the M.S. program. Companies snap up our M.Eng. graduates, at significantly higher salaries than they offer B.S. graduates.

WHY THE FIFTH-YEAR MASTER'S PROGRAM WORKS

The M.Eng. program grew out of a five-year undergraduate program that was in effect at the College of Engineering before 1965–66. In 1946, at the beginning of the highly charged post–World War II period, the faculty recognized that five years are needed to prepare for the profession of engineering—that a four-year curriculum is not sufficient, especially when it includes important nontechnical elements of general education. The solution adopted at that time was to extend the four-year program to five years (like one already in place in chemical engineering).

There were problems with the five-year baccalaureate degree, however. Cornell engineers had to spend five years, and extra tuition, to earn the same degree that other schools were awarding after four years of study. Those who wished to enter doctoral programs or occupations other than engineering after graduating from college were not well accommodated.

The solution to this problem was to establish a four-year baccalaureate degree program that could be followed by an integrated fifth-year program leading to a professional master's degree in an engineering specialty. The idea was to provide B.S. graduates with technical depth and design experience in a specific discipline before they started their industrial careers. This plan, adopted in late 1964, is still followed today, with some improvements that have increased the disciplinary scope, provided new ways of helping students financially, and expanded the opportunities for on-the-job professional experience.

As we see it, the chief benefits of the M.Eng. program are:

- engineering students can enter a different field or university after four years of undergraduate study;
- graduates from other universities can enter specialized engineering programs at Cornell and earn a graduate degree in one year;
- students well grounded in mathematics or the physical sciences can enter the professional program and receive an engineering degree;
- Cornell can attract very good students to an advanced engineering program.

Today the M.Eng. is offered in eleven fields, which are designated in the title of the degree—M.Eng. (Aerospace), for ex-

Figure 1

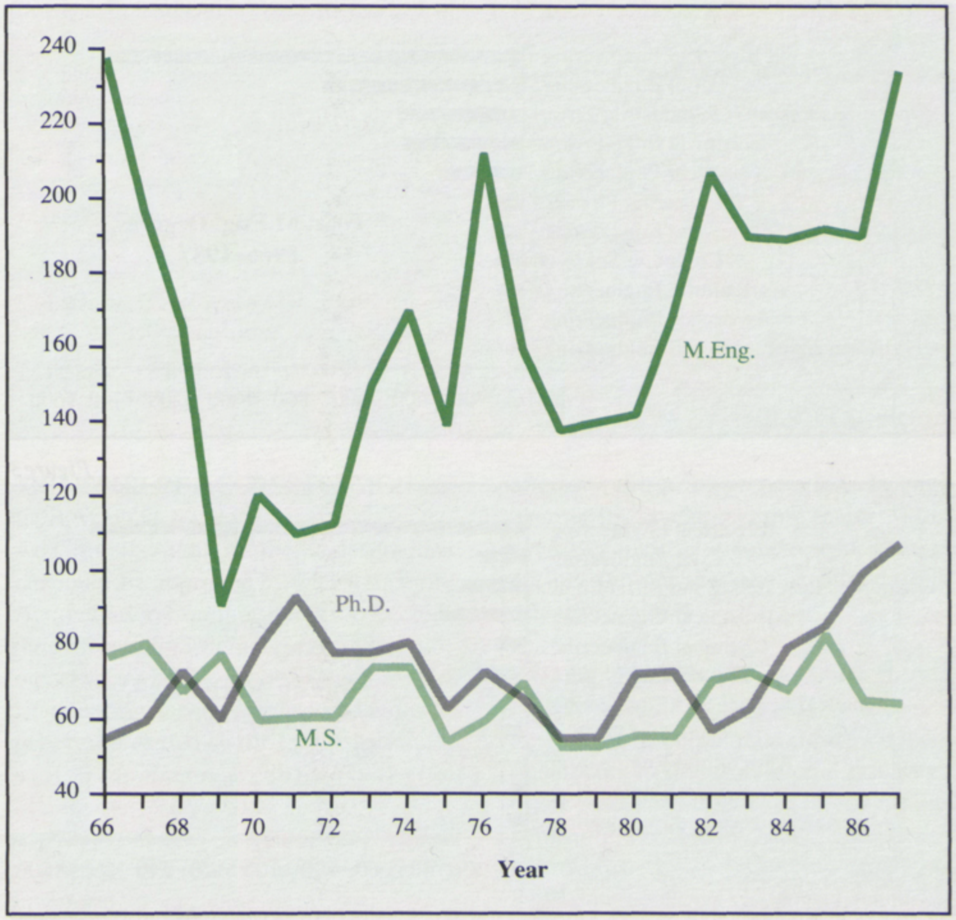


Figure 1. Since the beginning of the M.Eng. program at Cornell, the number of these degrees awarded has exceeded the numbers of M.S. and Ph.D. degrees in the corresponding engineering disciplines.

The large number of M.Eng. degrees awarded during the first three years of the program is accounted for by the fact that 1966 to 1969 was a transitional period between the five-year B.S. degree program and the five-year program culminating in the M.Eng. During these years, graduates holding the five-year B.S. degree could receive a semester's worth of academic credit toward the professional degree.

The reason the M.Eng. degree has become increasingly more popular than the M.S. degree is probably because the curriculum is shorter and because work on a design project rather than a thesis is more suitable for those who plan to become professional engineers.

Also evident in the figure is the recent growth of the doctoral program, attributed to Cornell's stature as one of the nation's great research institutions. A further significant rise will occur in the next several years as students now enrolled complete their studies. Because the research strength of the college and the university enhances the quality of the entire curriculum, this growth in the Ph.D. program also benefits the B.S. and M.Eng. programs.

ample. These eleven fields include the original eight—aerospace, chemical, civil, electrical, and mechanical engineering; and engineering physics; materials; and operations research and industrial engineering (OR&IE). Agricultural engineering and nuclear engineering were added later that first year, 1965, and computer science was added in 1970. A program in geological sciences has been approved and will begin admitting students next year.

A recent innovation was the introduction of a minor in manufacturing systems engineering. Students who take this option receive a Dean's Certificate in that specialty, as well as the M.Eng. degree. This option is most popular with students in OR&IE or in mechanical engineering.

Another option is a six-year program in which the student earns B.S., M.Eng., and M.B.A. (Master of Business Administration) degrees—a program that would normally require seven years of study. This program, most popular with OR&IE students, is administered cooperatively with Cornell's Johnson School of Management.

As demonstrated in Figures 2 and 3, the enrollment of students in the various disciplines is not evenly distributed. Electrical engineering has always been the most popular, and recently the distribution has shifted even more in that direction, to 56 percent of the total enrollment. Mechanical engineering is second, followed by OR&IE, engineering physics, and civil engineering. Computer science appears to be on the rise.

ENTRY INTO THE CORNELL M.ENG. PROGRAM

The requirements for admission to the program are such that a majority of Cornell undergraduates in engineering can enter if they have demonstrated both an interest in professional work, and the capability to be successful in it.

In practice, students with an undergraduate grade-point average below 2.7 (B–) are generally not encouraged to attempt the relatively challenging program. In several of the fields the minimum is set at 3.0 (B), and in one field—computer science—it is even higher.

In the spring of 1985, we began to admit a few Cornell undergraduates who were lacking not more than eight credits (about a half semester's worth of courses) to qualify for the B.S. degree. This allows the students to study full-time in their eighth semester and make progress toward the M.Eng. degree while completing the B.S.

About one-third of the M.Eng. students have undergraduate majors in a physical science, computer science, or applied mathematics, rather than in an explicit field of engineering. About one-fourth of the class comes from undergraduate schools other than Cornell.

HOW THE PROGRAM OPERATES IN THE COLLEGE AND UNIVERSITY

The M.Eng. programs are overseen by the Graduate Professional Programs Committee, which is composed of one member of each of the fields that offer a professional degree. It is headed by a chairman appointed by the engineering dean.

This committee is the policy-setting and administrative board of the Engineering Division of the university's Graduate School. It supervises admissions, certifies degree requirements, hears petitions from students, awards financial aid, and on occasion allows exceptions to formal procedures. To the students, the committee's most important function is recommending them for the degree after they have fulfilled the requirements.

Figure 2

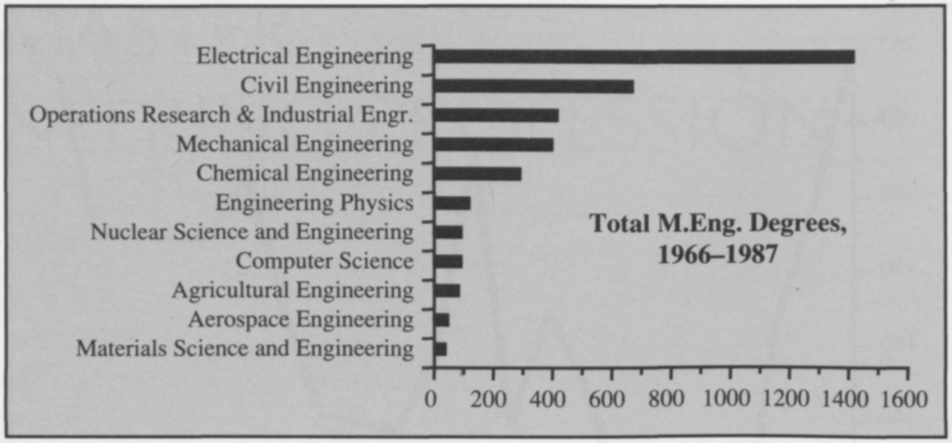
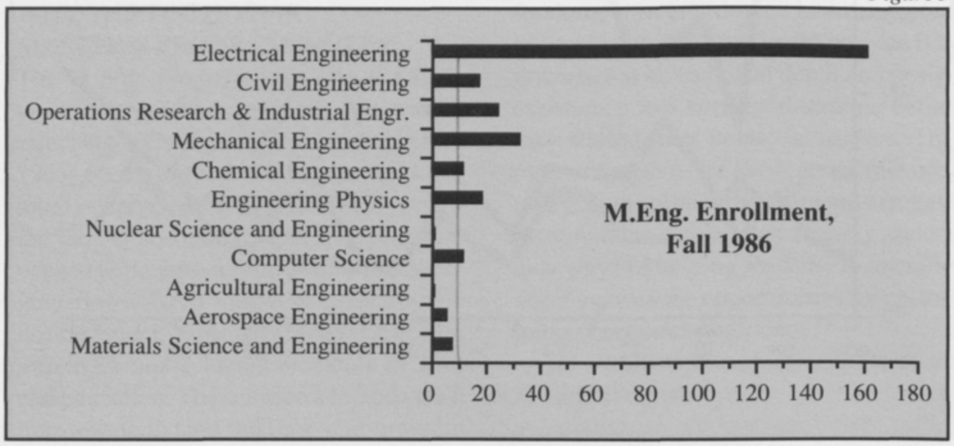


Figure 3



Chairmen of the Graduate Professional Programs Committee

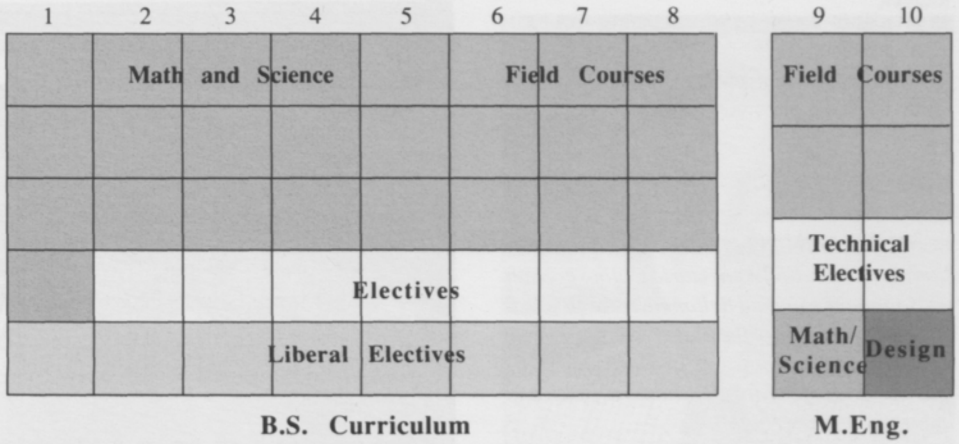
Julian C. Smith, Chemical Engineering, 1966–74
Thor N. Rhodin, Applied and Engineering Physics, 1974–78
John A. Muckstadt, Operations Research and Industrial Engineering, 1978–80
Ralph Bolgiano, Jr., Electrical Engineering, 1980–83
K. Bingham Cady, Nuclear Science and Engineering, 1983–87
Thor N. Rhodin, Applied and Engineering Physics, 1987–

Figure 2. A total of 3,658 Cornell M.Eng. degrees have been awarded in the fields indicated. Electrical engineering has been by far the most popular, accounting for nearly 40 percent of the total. Two of the fields—agricultural engineering and nuclear engineering—were added in the second year, and computer science was added in 1970. Geological sciences will be offered next year.

Figure 3. This was the distribution by field of M.Eng. students last fall. The total enrollment was 288, plus seventeen students who were on leave as interns in industry. The lead of electrical engineering has increased to 56 percent.

Figure 4. Typical curricula for the integrated B.S. and M.Eng. programs are diagrammed for the eight undergraduate semesters and the two graduate semesters. Each block represents one course, which might give three or four academic credits (usually four at the graduate level, which is required for the M.Eng.). Field courses are in the discipline that is the major subject.

The M.Eng. design course is a highlight of the program; it consists of project work carried out by an individual or a team, and is the equivalent of one or two courses. Some of this year's projects are described in other articles in this issue.



THE ISSUE OF ACCREDITATION FOR M.ENG. CURRICULA

At Cornell, eight of the undergraduate curricula are approved by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (EAC/ABET). None of the Master of Engineering curricula are accredited. This is because of two significant constraints:

- *Accreditation of a curriculum is given at only one degree level.*
- *An advanced program may admit Bachelors of Science only from accredited programs.*

A consequence of this policy is that if our M.Eng. program were accredited, we could not admit students who have a background in the physical or related sciences. We believe this is counterproductive, since in a technological society, the sciences are an important source of engineering innovation. I believe this policy is the reason that most schools around the country do not seek accreditation for their master's degree programs.

Our current practice is to accept both students with engineering degrees, and students who have majored in mathematics, a science, or computer science. We often require prior preparation in engineering for nonengineering majors, however; the qualifying course work is taken during summer sessions or an additional semester.

PROVIDING FINANCIAL AID FOR M.ENG. STUDENTS

Several forms of financial aid are available to students in the professional programs: merit-based scholarships, teaching stipends, and company scholarships and internships.

Endowments provided by friends and alumni bring in about $330,000 a year for financial aid. Benefactors' names that have become familiar to M.Eng. administrators include Howard A. Acheson '23 and Howard A. Acheson, Jr. '50, John L. Collyer '17, Lester B. Knight, Jr. '29, William L. Lewis '22, John McMullen, Anabele G. and George A. Post, and William S. Hansen '49 of the A. Stucki Company.

Typically, about 60 percent of the endowment income is awarded as merit-based fellowships and 40 percent as teaching stipends. A teaching stipend of $3,300 a year requires the student to work eight hours a week during the academic year on teaching-related activities. This compensation is equivalent to $13 a hour, which, although generous, does not come close to being enough for "working one's way through college." The faculty believes that participation in the teaching process is beneficial for graduate students for two reasons: they relearn and think about the analytical foundations of engineering, and they develop communication skills.

Grants from corporations are another source of fellowships. For instance, this past year there were ten General Motors fellows and thirty One-Year-on-Campus (OYOC) scholars supported by AT&T Bell Laboratories. The General Motors fellows were studying in various disciplines; most of the OYOC students were in electrical engineering, though two were in computer science.

INTERNSHIP IN ENGINEERING: A NEW OPPORTUNITY

An important recent development is the establishment of the Internship in Engineering Program, which gives the students opportunity to gain "on-the-job" professional experience as part of their degree

On the job at NCR in Ithaca, M.Eng. interns Martin Tomasz and Annemarie Colino consult with operator Edmund Bellamah in the printed-circuit-board area of the plant.

Tomasz is specializing in electrical engineering, and Colino in operations research and industrial engineering.

program. (It is similar to the undergraduate Engineering Cooperative Program.)

An internship is based on interactions among the student, the company, and Cornell. Generally the student spends the initial fall semester at the university, then a calendar year as a company employee, and finally a spring semester on campus. The company provides a salary or the equivalent during the work period, and covers tuition and fees during the two academic semesters.

An obvious benefit of the program is that it provides on-site engineering experience and significant financial support for the students. The company benefits by gaining access to potential permanent employees who have professional perspective and experience. It often happens that the intern is offered, and accepts, regular employment after graduation.

An additional important result of the internship program has turned out to be the identification of good design projects for the students to continue working on back at the college. In fact, it has often happened that the student, the professor who is supervising the project, and the company engineer develop a mutual interest. In some cases, the project is carried out on the industrial site under the joint supervision of a plant engineer and the professor.

About half the internships are funded by restricted gifts to Cornell. A company gives, say, $44,000 to the university with the restriction that it be used to pay tuition and fees for an intern and provide that student with a stipend spread over the twenty-one months of the program (nine months at Cornell and twelve at the company). In this way the intern is a student, registered in absentia, during the work period and is provided with fringe benefits

Corporate Participants in the M.Eng. Internship Program

Alcoa	Hughes Aircraft
Allison	IBM
AT&T Bell Labs	Kodak
Burroughs (UNISYS)	Moog
Carrier	NCR
Continental Can	Phillips ECG
General Electric	Raytheon
General Motors	Schlumberger

through Cornell. There is no social security tax on stipends, and because the income is distributed over three years, the student's income tax is lower than it would be for one calendar year.

The cost to the company is no greater than it would be if the student were hired in the usual manner for a year's time. For example, if the salary were $30,000, fringe benefits and social security taxes would add another $14,000 or so. In other words, for the same $44,000, the student can be provided with tuition and fees at no real cost to the company!

This seeming bit of magic was brought to our attention by Cliff Wagoner '62 of Schlumberger Well Services, who has helped greatly in developing the program and has arranged eleven internships over the past few years.

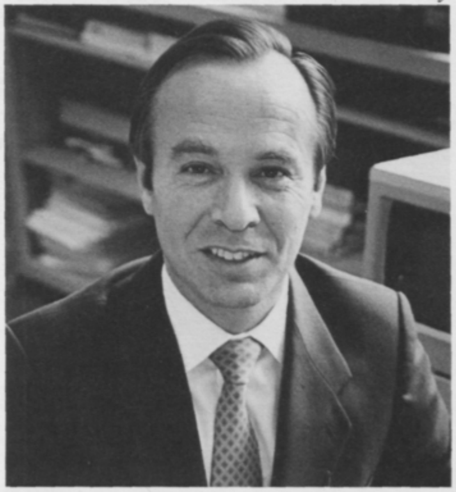
THE BOTTOM LINE: PREPARATION AND COST

The bottom-line questions are "Is the M.Eng. graduate properly prepared to enter high-technology engineering?" and "Is the additional cost of the fifth year, in time and money, justified?"

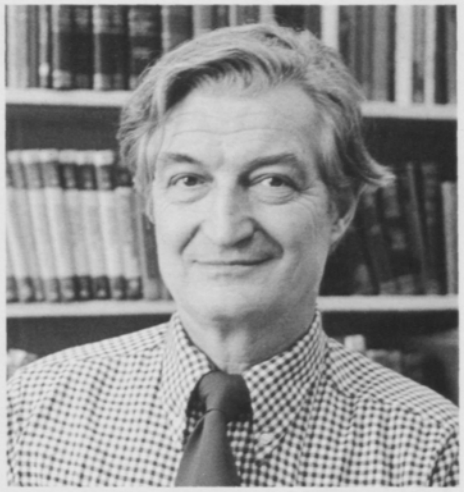
The answer to both questions is a resounding "Yes!" Testimonials from graduates and their employers answer the first one, and the growing size of the program and data on salaries answer the second.

Mark Savage, the college's placement coordinator, reports that average starting salaries in 1986 were $28,900 for B.S. graduates and $34,500 for M.Eng. graduates. In ten years the difference (in 1986 dollars) would be $56,000. This far exceeds the probable cost ($40,750) sustained by the M.Eng. student for tuition ($11,500 in 1985–86), room and board ($7,500), and foregone salary for nine months ($21,750).

Cady



Rhodin



Furthermore, this comparison does not take into account the value of the superior preparation M.Eng. graduates have, and the likelihood that they will progress more rapidly in the company.

The obvious conclusion is that B.S. graduates who want an advantageous entry into the engineering profession and can qualify for admission should go for the fifth-year M.Eng. degree, even if it is at their personal expense. An increasing number of employers both in well established engineering firms and in areas of new technology recognize that the Cornell M.Eng. program is professional engineering education at its best.

K. Bingham Cady, the author of this article, has just completed a term as chairman of the Graduate Professional Programs Committee at the College of Engineering. Thor N. Rhodin is the new chairman.

Cady is the associate dean for college affairs as well as a professor of nuclear science and engineering and of applied and engineering physics. He also serves as director of the undergraduate Engineering Cooperative Program.

He holds a doctorate in nuclear engineering from the Massachusetts Institute of Technology and has been on the Cornell faculty since 1962. He has served as a consultant in nuclear engineering to a number of companies and national laboratories. He has had industrial experience in his undergraduate major field, naval architecture and marine engineering.

Rhodin, professor of applied and engineering physics, brings experience with the M.Eng. program to his new appointment, since he served a previous term as committee chairman (1974–78). He was a member of the committee that originated the proposal for the establishment of the M.Eng. program.

Rhodin received his Ph.D. from Princeton University in 1946. Before joining the Cornell faculty in 1958, he was a staff member of the Institute for the Study of Metals, now the James Franck Institute of the University of Chicago, and then a member of the engineering research staff at E. I. du Pont de Nemours.

A specialist in the physics and chemistry of surfaces and interfaces of metals and semiconductors, Rhodin is a fellow of the American Physical Society and was a recipient of the Alexander von Humboldt Senior Scientist Prize.

TESTING RACE-CAR MODELS IN CORNELL'S WIND TUNNEL

Next to testing a real race car, the most exciting project for a racing-buff engineering student may well be testing a race-car model. That was the assignment Gregory Hock was given for his M.Eng. (Aerospace) design work.

Greg, who has taken a job with McDonnell Douglas Astronautics Company in Longbeach, California, completed his degree work this summer. He is interested in the aerodynamics of all kinds of fast vehicles—race boats as well as race cars and airplanes.

Testing the model car involved high-powered engineering more than high-powered engines, however. The object was to study the effects of structural features on the flow of air underneath an idealized model of a venturi-type race car, and therefore on the car's performance. The study was based on previous work by Professor Albert R. George and his former student J. E. Donis.

AERODYNAMIC STUDIES OF VENTURI MODELS

Increasing the efficiency and stability of passenger automobiles and improving the performance of race cars are the dual incentives behind a recent upsurge of interest in automobile aerodynamics, according to George.

For passenger cars, the main factor is *drag*, and since some of the drag is associated with the phenomenon of *lift*, designers are interested in ways of reducing positive lift (which is good for airplanes but not for cars). Race cars actually need negative aerodynamic lift, or *downforce*, to allow them to hold the road while speeding around corners. In most situations, overall race-car performance is better with increased downforce even if this is at the expense of a significant increase in drag.

The Cornell work has focused on the effects of lift and drag of air flow *underneath* vehicles. Some of the testing has been on the venturi configuration, which is characteristic of race cars. This structure first accelerates and then diffuses the air flow coming in under the front of the car, thereby generating low pressures (and negative lift) underneath.

Cornell researchers discovered that the flow beneath a venturi model is three-dimensional and dominated by a pair of longitudinal vortices between the bottom of the vehicle and the ground. These vortices are created by air flows that come in under the side edges because of the lower pressures under the vehicle. To study the mechanism of vortex formation, various modifications of a basic model can be tested in a wind tunnel. Such modifications include the addition of side pods, a "tub" in the center, skirts of different shapes, and "bumps" to simulate wheels.

Figure 1

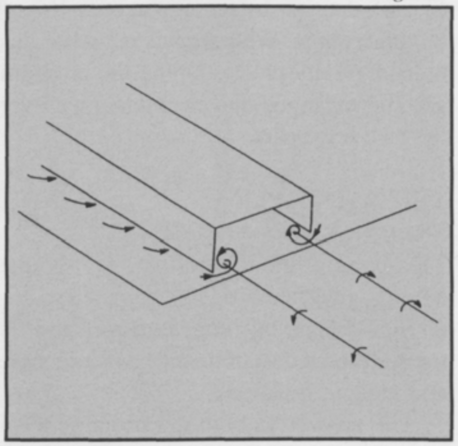


Figure 1. Downforce in a venturi race car is increased by a pair of vortices that form beneath the body as a result of the inflow of air under the side edges.

Right: Gregory Hock inserts the vortex probe into the wind tunnel. The object in the tunnel is the idealized race-car model.

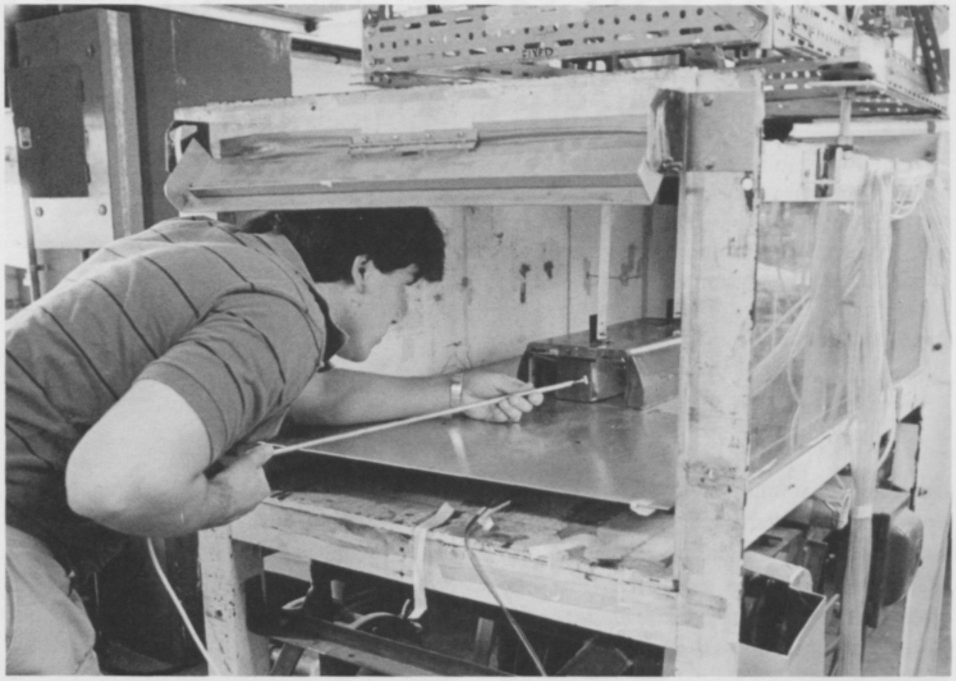
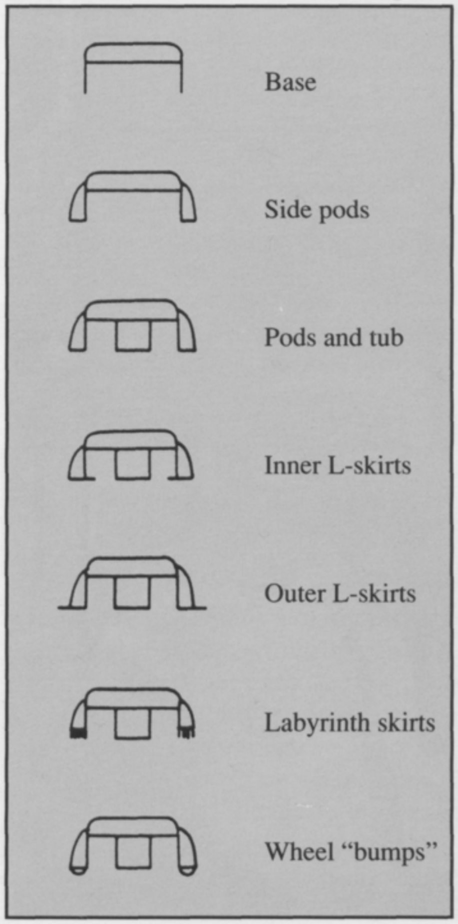


Figure 2. These modifications of the venturi model are among those that have been tested in the wind tunnel at Cornell.

Figure 2



This earlier work was sponsored partly by Newman-Haas Racing, and some of the results were used in building a car that was raced by Mario Andretti in several Indianapolis-CART races.

USING THE WIND TUNNEL IN M.ENG. PROJECT WORK

Hock's job was to measure the effects of various design features by testing the model in the low-speed wind tunnel in Upson Hall. This tunnel is about 50 feet long and has a Plexiglas-enclosed test section about three feet long. The model is suspended in the test section.

Attached to the top of the test section is a balance, designed by George and his students, that measures lift, drag, and pitching moment—parameters needed to calculate the lift coefficient.

Other instrumentation includes a vortex probe especially designed and built by Hock with the help of Edward Jordan, research support specialist in Upson Hall. The probe is a metered paddlewheel that can measure the vortex in different parts of the venturi stream.

Working with the wind tunnel has been valuable experience in itself, Hock remarked. With a model in the tunnel, even the complicated aerodynamics of air flow beneath a race car can be measured and understood.

MEASURING THE FRACTAL GEOMETRY OF TURBULENT FLAMES

Turbulence complicates the design of combustion systems such as those in automotive engines and gas turbines. A major effect of turbulence is to wrinkle flame sheets into very complex shapes not easily described by combinations of simple geometric shapes. To model the combustion system, a designer needs, instead, the new mathematical tool of fractals.

This problem was a challenge for two of this year's M.Eng. students in engineering physics. Scott Hilton and Theodore Lamb worked with Professor Frederick C. Gouldin of the mechanical and aerospace engineering faculty, whose research is in the broad area of the fluid dynamics of combustion. Gouldin recently developed a model of turbulent combustion based on a fractal description of wrinkled flame sheets—a model that can be tested and augmented by experimental measurements of a kind undertaken by the two students.

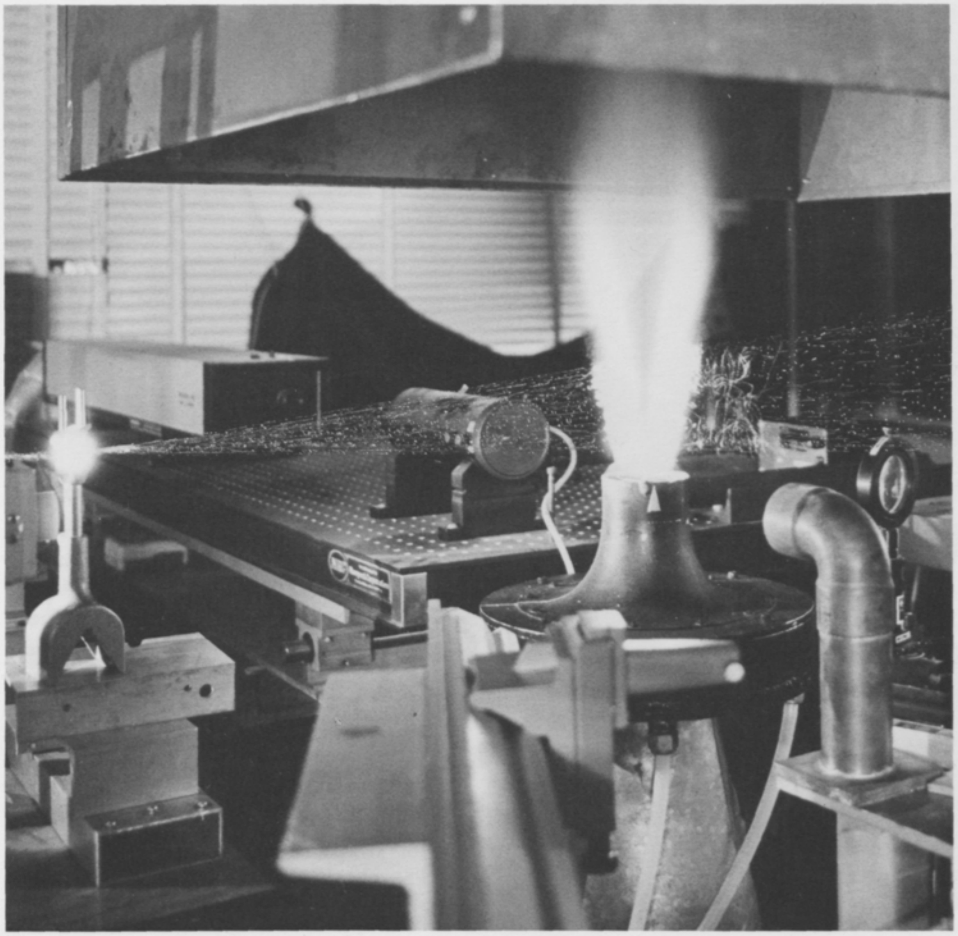
Gouldin's model assumes that the wrinkling of the flame sheet extends over a wide range of measurement scales—that is, that the flame surface has a fractal dimension, somewhere between 2 (the dimension of a smooth surface) and 3 (the dimension of a space-filling object). The fractal is a measure of the surface "roughness": the greater the dimension, the rougher and more wrinkled the surface.

THE EXPERIMENTS AND WHAT THEY SHOWED

Hilton and Lamb worked on different aspects of the same general approach, which is to use laser light to "capture" the flame geometry, and fractals to characterize it. Hilton used the technique of laser tomography to obtain a visual cross section

Below: Theodore Lamb (at left) and Scott Hilton (right) worked with Professor Frederick C. Gouldin (center) on the measurement of fractal dimensions of flame surfaces.

Both students completed their M.Eng. (Engineering Physics) degree work this spring. At this writing, Lamb had accepted a job with Pratt and Whitney Aircraft Engines, where he will work on the design of turbine blades for jet engines. The two students, who have been friends since their undergraduate years, shared an apartment as well as a laboratory and were pleased to work on projects that are part of the same research program.



In the experimental setup, a sheet of laser light formed by the cylindrical lens (at left) illuminates the flame (at center) from the combustion of methane. The sheet of laser light is made visible by scattering from dust particles.

A color photograph of the flame, reproduced on the cover of this issue, dramatically shows how the laser illumination makes the flame surface visible. The green color is from light scattered by oil droplets "seeded" in the combustion mixture; this color marks the presence of reactants. The dark region is the product zone. The wrinkled flame surface is visible as the boundary between the illuminated (green) and the dark regions.

of a flame surface; Lamb focused on a single point and made measurements over time.

In Hilton's experiment, a laser beam was used as a measuring tool to study turbulent V-shaped flames from the combustion of premixed methane and air. The mixture was made turbulent to the desired degree by passing it through a wire screen. A pulsed laser beam in the visible (green) region was used to illuminate the flame with a sheet of light, images were recorded by camera, and the photographs were digitized and analyzed for fractal dimension using a special computer program developed by Hilton.

In this laser tomography method, the cross section between the flame surface and the sheet of laser light is made visible by seeding the combustion mixture with a cloud of silicon oil droplets: light scattered by the tiny droplets "lights up" the unburned gas, but because the droplets evaporate when they cross the flame boundary, the product zone remains dark. The interface between light and dark is the zone of interest; the fractal dimension of the surface is obtained from that of the intersection curve. Fractal dimensions in the expected range, slightly above 2, were obtained.

Lamb's method was to measure the time record of the turbulent surface as it passes from one side to the other of a fixed point. The record is obtained by observing the light scattered from a continuous laser beam. When the signal is high (due to scattering from oil), reactants are present; when the signal is low, products are present; changes in the signal mark a passage event. In the case of the V-shaped methane-air flames, the records were found to have fractal characteristics. Furthermore, Lamb's results were consistent with Hilton's.

As applied physics students, Hilton and Lamb were interested in the combination of theory and experiment that their problem involved, and in the potential applicability of the work.

Although the experiments showed that more data are needed to make useful correlations between flame conditions and fractal dimensions, the students believe their results demonstrate the validity of the theory and the usefulness of the technique.

"REAL" M.ENG. (CHEMICAL) PROJECTS DRAW ON CURRENT TECHNOLOGY

The imminent replacement of the huge three-story-high Unit Operations Laboratory in Olin Hall with a much smaller two-story bay and several single-story laboratories is evidence of change not only at Cornell, but in the whole of chemical engineering. Modern techniques have changed the ways in which chemical engineers go about their jobs.

Largely responsible is the current use of more compact and better designed and instrumented equipment, and of computers for simulation. These innovations, many of which originated in university research, are reflected in the academic programs. For example, consider a sampling of the 1987 Master of Engineering (Chemical) design projects at Cornell.

A NEW TECHNOLOGY FOR ALCOHOL PRODUCTION

In a project directed by Professor Michael L. Shuler, M.Eng. student Steve Letai worked on the design of a plant that would produce ethanol using the new technology of a multimembrane biofermentor. Support for the project is being provided by the Department of Energy through its Energy Conservation and Utilization Technology (ECUT) program, which is administered by the Jet Propulsion Laboratory. The economics of such a plant were analyzed, and the process was compared with the traditional method using batch fermentation.

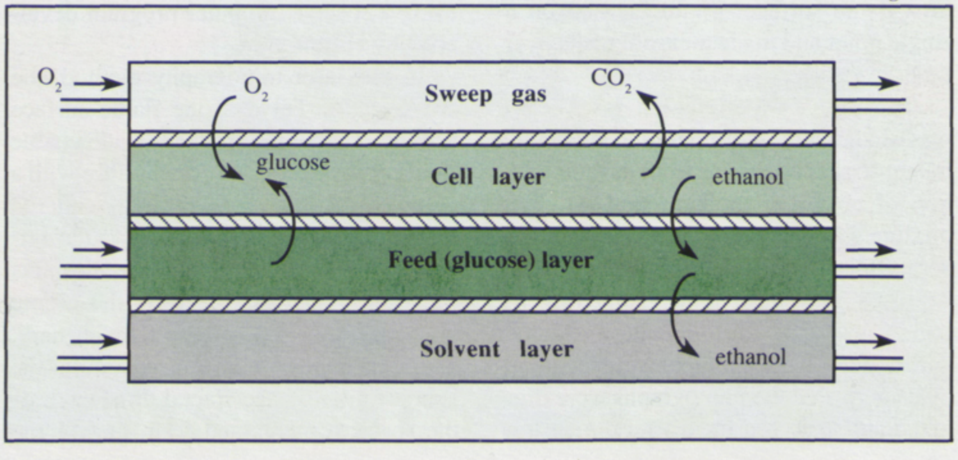
In the biofermentor reaction, glucose is converted to ethanol in a process moderated by yeast cells. A hydrophobic membrane separates the sweep gas from the cell layer, and a hydrophilic membrane separates the cell layer from the feed layer. Glucose from the feed layer diffuses into the cell layer, where it is converted to ethanol. But since a buildup of ethanol

Figure 1. A schematic diagram of the basic multimembrane biofermentor illustrates how glucose is converted to ethanol in a reaction mediated by yeast cells.

A hydrophobic membrane separates the sweep gas (oxygen) from the yeast-cell layer; a hydrophilic membrane separates the cell layer from the feed layer; and a hydrophobic membrane separates the feed layer from the solvent layer. Product ethanol is drawn off with solvent and separated out.

If more surface area is needed for the hydrophobic membrane between the feed and solvent layers, this can be achieved by the use of hollow fibers instead of a flat membrane.

Figure 1



inhibits continued production, the ethanol is kept at low concentration by extracting it with the solvent tributyl phosphate (TBP). Later the ethanol is recovered and the solvent is recycled.

One of the valuable results of the Cornell project was the discovery of how to use TBP as the solvent in the process without killing the yeast cells. According to Shuler, the Cornell group was the first in the world to show explicitly that solvent toxicity can be due to direct interaction of yeast cells with droplets of emulsified solvent. In the Cornell experimental reac-

Left: One of this year's M.Eng. (Chemical) projects concerned the separation of antibiotics from solution. Ron Challa worked with Professor Robert K. Finn on a feasibility study of a process in which 6-aminopenicillanic acid would be crystallized directly from a broth containing penicillin G. The procedure would eliminate several steps from the traditional process.

The problem involved first a determination of the optimum conditions for the crystallization. The second phase, a comparison of costs associated with the proposed and the traditional methods, requires the use of a specially developed computer program.

Above: Another project this year concerned air-pollution control. Here Professor Peter Harriott discusses their project work with M.Eng. students Melissa Hamkins and Joseph Ledoux.

The problem they studied was the removal of small amounts of hexane from the gas stream emitted in the industrial process of extracting oil from soybeans. The hydrocarbon must be removed before the gas is emitted to the atmosphere. The students investigated the three primary removal methods—incineration, absorption in oil, and adsorption on activated carbon—in terms of capital and operating costs. (Adsorption was found to be the best.)

tor the hydrophobic membrane prevents emulsification of TBP in the feed layer.

The project work involved laboratory investigation of two modes of separating the ethanol and the solvent. Distillation was found to be better than air stripping because, although it is less energy-efficient, a smaller column is required. The data obtained helped in the design of the distillation column.

Letai's report pointed out some other economically important factors. For example, a solvent with a higher distribution coefficient would greatly improve the economics of the multimembrane system.

A major part of the project was to assess economic feasibility. Letai found that large-scale production—at the level of 100 million liters or more per year—would be more economical by the batch fermentation method, but that at lower production rates—between 40 and 100 million liters per year—the costs of the two processes cross over. "Though our new technology is not yet economical for highly centralized production of ethanol," Letai's report concluded, "it has great potential for decentralized operations and for the production of specialty chemicals."

COMPUTER SIMULATION OF A POLYMERIZATION REACTION

The continuous stirred-tank reactors used to produce polymers are often operated under conditions such that minor disturbances can lead to excessively high temperatures. Damaged equipment and ruined product can be the result.

M.Eng. student Trevor D. MacArthur, working with Professor Peter Harriott, investigated the problem of reactor stability by means of a computer simulation of the process. The project included the development of suitable control algorithms.

The system MacArthur studied is the polymerization of methyl methacrylate in solution, with benzoyl peroxide as the initiator. (This polymer is sold under tradenames such as Lucite and Plexiglas.) The conversion is controlled by the rate at which the initiator is fed into the reactor, and the temperature is controlled by regulating the mixture of warm and cold water admitted to the cooling jacket. The object of the project was to study how these two control loops interact, and to develop a way of determining what controller settings would be best for an inherently unstable reactor.

MacArthur's model was derived from mass and energy balances, with use of heat capacities, heat-transfer coefficients, and kinetic parameters obtained from the literature. The simulation was done on one of the school's MicroVax computers. About one thousand minutes of reactor operation could be simulated in about six minutes of computer time.

The study showed that stable operation of the reactor could be obtained over a range of controller gains, but that the best settings differed significantly from those recommended on the basis of previous studies of simpler (stable) systems.

THE M.ENG. PROGRAM AND ITS PRODUCTS

Professor Robert L. Von Berg, who coordinates the M.Eng. (Chemical) program, notes that both the projects and the course work are practical in nature, and the graduates (ten or so a year) generally go to work for industrial companies. Often they are employed in technical jobs, but many of the students take business courses as part of their degree program, and develop careers in the management side of the chemical industry.

Industrial input benefits the program in several ways, Von Berg pointed out. In the past two years, for example, three of the M.Eng. students (all women, as it happens) participated in the recently organized internship program; they were sponsored by and worked for Eastman Kodak, General Electric, and General Motors. Also, several of the project problems this year were suggested by companies. Air Products and Chemicals, Inc., for instance, consulted with two students who worked on the design of a low-pressure methanol plant to be integrated with a coal-gasification process for peak electric power production.

The Cornell M.Eng. (Chemical) program demonstrates how academia and industry can interact effectively in a discipline that has direct practical applications. The students work in classroom and laboratory with professors who are at the leading edge of theoretical and technological developments. And their project work focuses on the use of current techniques in tackling real industrial problems.

M.ENG. DESIGNERS PLAN LOCAL WASTE-DISPOSAL SYSTEMS

Solid-waste disposal was a hot topic in Tompkins County, New York this spring. The county was confronting the highly charged issue of where to locate a badly needed dump. That infamous garbage barge was still cruising the Atlantic coast, looking for a place on land to deposit its cargo. It all added a touch of drama to the Master of Engineering (Mechanical) design project, which this year centered on waste-disposal systems for Tompkins County and Cornell University.

The group of fifteen M.Eng. candidates were divided into three teams, all under the supervision of Professor Robert L. Wehe. One team studied the solid-waste disposal system currently in use at Cornell and considered several alternatives. The other two teams worked on plans for the county. All three teams prepared detailed reports which they summarized at a presentation shortly before the end of the spring term.

ANALYZING THE NEEDS, INVESTIGATING THE OPTIONS

The first job of the teams was to make a thorough study of available technologies and of the needs of the clients—Cornell University or Tompkins County. The stu-

Above: Professor Wehe meets with one of the M.Eng. teams in the Upson Hall lobby just before the formal presentation of design reports. This group worked on a solid-waste disposal plan for Cornell. From left to right are E. Cheng Lin, Kenneth Hey (team leader), Francisco Suro, Professor Wehe, Sonja Somdahl, and Mark Cicciari.

The team that studied a recycling and incineration system for Tompkins County consisted of Henio Arcangeli, Jr. (leader), Syed Hasan, Jose Luque, Wai Yuen Lum, and Kristina Rothley. A county system that would use incineration only was considered by Ruben Marecos (team leader), Christopher Gaechter, Kuang-Hui Chang, Jorge Otero, and Chenter Ying.

dents compiled information on the volumes and kinds of refuse, and studied the existing facilities and operations.

The county generates 200 tons a day of solid wastes, largely garbage, which is deposited in landfills. (The one that is most used must be closed because of the danger of groundwater contamination, which is why a new dump site must be found.) Cornell, with a peak population of more than 26,000, generates more than 9,000 tons of solid waste a year—some 26 tons per day during the times that classes are in session. This includes paper, plastic, glass, metals, and organic matter collected in different proportions from different kinds of buildings.

As part of the preparation, Wehe and groups of students visited an $80-million recycling plant near Rochester, New York, a compaction and landfill operation near Elmira, New York, an incinerator in Oswego, New York, and a "refuse-to-energy" facility in Baltimore, Maryland.

The timeliness of the topic was emphasized by the disclosure early in the summer that a state-funded center for research on solid-waste disposal may be established at Cornell.

In past years some of the M.Eng. (Mechanical) projects have included design work on vehicles that were actually built.

The top photograph on the opposite page shows a roving vehicle designed for exploration on Mars. Work on this project, sponsored by NASA, extended over several years.

Project work on the Cornell Electric Car is pictured at left below. This experimental vehicle for urban use was worked on for a number of years by student teams in electrical engineering as well as mechanical engineering.

At right is a high-speed bicycle with streamlining features designed with the aid of wind-tunnel testing and computer calculations.

WASTE-TO-ENERGY: THE PROPOSAL FOR CORNELL

The student team considering the solid-waste disposal system at Cornell based their design on an estimated average of 9,000 tons per year collected from the 180 buildings on the main campus.

The results of a 1982 study indicated that the dining facilities account for about 24 percent of the total volume of the waste stream, dormitories about 30 percent, and academic buildings about 46 percent. The kinds of refuse from the three sources are quite different, of course: wastes from the dining halls is half "wet" garbage, for example, and waste from the academic buildings is 93 percent paper.

The present method of disposal of ordinary refuse (not toxic or otherwise special) is to contract with a private company to make daily collections by truck and deposit them in a county landfill. The cost was estimated by the students at about $28 a ton. The county does not charge a tipping fee. A drawback cited by the team is the rising cost of landfill disposal, partly because of stricter regulations such as requirements for leachate liners, leachate drainage, and water-monitoring wells. Also, the county landfills have limited capacity, and less refuse from Cornell would mean they would be usable for a longer time.

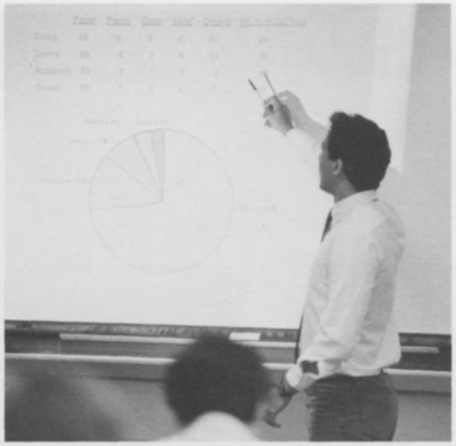
Several possible processes were examined. One involves shredding to yield a material called fluff, followed by burning as refuse-derived fuel. The combustion could be accomplished at Cornell in an existing boiler, but because of the high cost of the shredding equipment and various handling problems, the method was not recommended.

Recycling was appealing because it would reduce the volume of waste and conserve resources. A serious problem at the present time, however, is that the market for scrap is very poor. The team's report noted that the economic situation caused the city of Rochester to abandon its expensive new separation equipment and revert to landfill without recycling. The situation at Cornell is especially unpromising because the kind of waste generated has a relatively low content of the most valuable materials, notably metals.

Still, the team suggested that the university could consider recycling more of the paper from the academic buildings (a small amount separated by the building personnel is now recycled). There would be problems, of course. A shredding and blowing process would have to be used, partly to avoid contamination by hazardous metals from, for example, discarded pocket-sized batteries. Also, the 6,000 tons or more of scrap paper that would be salvaged per year might be more than could be sold, at least on the local market.

Co-composting of the dining-hall waste, although ecologically sound and potentially a source of revenue from methane generation, is still in the developmental stage and therefore not yet practical for Cornell.

The alternative the team finally chose for their design effort is incineration with energy recovery in the form of steam for heat or cogeneration. "By landfilling all its solid waste, Cornell is throwing away about 1,123,200 therms of fuel," they pointed out in their report. This represents about 8 percent of the university's energy needs that are now supplied by coal, oil, and natural gas. Cornell's waste is especially well suited for this process because of the high volume of paper, which has a high BTU value. In addition to conserving



Right: At the formal presentation of M.Eng. (Mechanical) design reports, Francisco Angel Suro presented part of the team report on possible revisions of Cornell's solid-waste disposal system.

energy, this technology would have the advantage of reducing the volume of waste for landfill disposal by 85 to 95 percent, thereby prolonging the life of the county landfill.

MAKING SPECIFIC DESIGN RECOMMENDATIONS

The team recommended the purchase of a modular incinerator, preferably a "starved air" model, which has high efficiency and low emissions. The unit would have a built-in device for scrubbing the gaseous effluent.

Aspects considered in the analysis included handling of the refuse (delivery by truck to a tipping area in a specially designed building) and of the ash (truck transport to the landfill). The plan calls for installation of a sprinkler system in the storage area to extinguish possible fires from spontaneous combustion, and the purchase of a front-end loader to transport the waste from the tipping area to the incinerator. Consideration was given to the location of the facility, which should be as close as possible to the power plant.

The final step was a detailed cost evaluation. The total capital investment was estimated at about $3.6 million, and the annual operating cost at about $347,000. (Cornell pays the local waste-removal company about $261,000 a year.) The effects of a number of variables, such as interest rates, the price of fuel that would be replaced, and possible reductions in capital expense, were estimated. For example, the calculations showed that the cost of fuel oil would have to rise 68 percent from its current level to make the proposed plant economically advantageous for the university.

STUDIES OF COUNTY WASTE-DISPOSAL SYSTEMS

Similarly detailed analyses were made by the two M.Eng. teams considering plans for solid-waste disposal in Tompkins County. One system involved recycling and incineration, and one was based on incineration alone.

The chief problem with a recycling process, Wehe remarked in commenting on the students' designs, is the current depressed state of the market for recycled materials. A solution, he said, would be for governments to provide economic incentives for industrial use of these materials. The problem of waste disposal is one that society must face, he said.

The system he would favor for Tompkins County is incineration, which would make the landfills last five times longer. One of the problems would be the emissions, which should be passed through a scrubber even though that is not legally required.

M.ENG. DESIGN PROJECTS OVER THE YEARS

This year's design project was unusual in that it did not entail actual construction of a mechanical device. In past years the student teams have worked on the design of such things as a high-performance wheelchair, an autonomous roving vehicle for exploration on Mars, electric cars, and devices for more accurate metering of dispensers at soda fountains.

The wheelchair project was undertaken because of a student who would benefit from a chair with special provisions. The Martian roving vehicle project resulted in an operating machine that was demonstrated to NASA, which had sponsored the work. Several electric-car models, developed in cooperation with electrical engineering students, were built and driven around campus. Other designs never materialized into real prototypes.

Another recent project was the development of a reliable and economic way of detecting knock in an internal combustion engine. Professor Edwin L. Resler, Jr., whose research program includes work in this field, consulted on that project.

Whatever the specific project, the benefit to the students is the opportunity to learn the design process through practice.

ON BIRDSONG AND ELEPHANT CALLS

People who cannot hear frequencies in the range of human speech, or who want to hear sounds humans were never intended to hear, may benefit from projects recently carried out by Cornell M.Eng. students.

The story begins in the fall of 1985, when two humans of the second sort approached Electrical Engineering Professor Paul McIsaac with a problem. As research associates in Cornell's Laboratory of Ornithology, they wanted to hear and record low-frequency (infrasonic) sounds made by elephants. (Perhaps only at Cornell could researchers in an ornithology laboratory be concerned with elephants—animals that not only lack feathers, but are also not known to fly ["with one notable exception!" cautions Charles Walcott, executive director of the bird lab]).

McIsaac thought the problem would be a good subject for an M.Eng. design project. I was recruited as adviser because of my previous work with audio and electronic-music synthesis. As the idea developed, it expanded in scope to encompass three different projects, and six students became Masters of Engineering (Electrical) in the course of developing the needed instrumentation.

FREQUENCIES HUMANS ARE DESIGNED TO HEAR

In all three projects, the instrument that needed augmentation is the human ear.

People with normal hearing can detect frequencies as low as 15 Hz and as high as 15 kHz or more. A more usual or "comfortable" range would be from about 100 Hz to 10 kHz. This range serves us well for human speech, which is in the range of about 100 Hz to 3 kHz, and for most other sounds we humans expect to hear.

Problems come up, of course, when an individual suffers a hearing loss that affects the range of frequencies heard. A loss in the high-frequency range often occurs as people get older, for instance. For many people with frequency-related hearing loss, the usual type of hearing aid (basically just amplification) is not much help.

Additional problems can occur when people—like the elephant-call researchers—try to hear sounds that are outside the range of ordinary human hearing.

DETECTING LOW-FREQUENCY ELEPHANT CALLS

The elephant-call project was proposed by research associates Katy Payne and Bill Langbauer. Their interest was explained by the fact that the Library of Natural Sounds at the ornithology lab documents many animal sounds—mostly, but not entirely, bird calls. That first fall, M.Eng. students James Rotar and Napoleon Lee began work on the project, and this year Gregory Manganello joined the team.

At first the students worked on two problems simultaneously, a circumstance that turned out to be fortuitous. One problem was how to detect the low-frequency (around 20 Hz) elephant sounds and translate them up into a range comfortable for human hearing. The second problem involved recording four infrasonic channels and synchronizing them with the video recordings the researchers would be making. It appeared that a special—and expensive—new FM tape recorder would be required.

The initial idea for the translation problem was to use frequency shifting (single sideband modulation with an audio-frequency carrier). It turned out that another method was actually used, but in thinking about modulation at low bandwidths, we got an idea for tackling the recording-and-synchronization problem. In a very close

M.Eng. (Electrical) students developed a device to translate low-frequency elephant calls to a range more easily heard. These are Asian elephants, studied and photographed in research for the Library of Natural Sounds at Cornell.

mimic of a radio broadcasting technique, we used the four channels of low-frequency sound to amplitude-modulate carriers in the kHz range of audio frequencies; all four modulated signals could then be summed and recorded on one of the two audio channels of the video recorder. The low-frequency sounds could be recovered by demodulation—bandpass filtering of the carriers followed by envelope detection. The need for a special audio recorder was gone, and the synchronization with the video was automatic. The modulator box was constructed by Jim Rotar's "crew" and went with Payne and Langbauer to Africa for field use in the summer of 1986.

The upward translation was not done with a frequency shifter because that would simply provide a constant shift. The problem with a constant shift is one of detection. As an elephant "sings" some sort of "tune", the frequency may vary from, say, 20 Hz to 22 Hz. This is equivalent to about a whole tone on a musical scale. But if a frequency shift of 200 Hz is put on this, the result is a variation from 220 to 222 Hz, only about one-sixth of a halftone—an interval not very noticeable to a human listener. A proportional shift, say from 200 to 220 Hz, would be better.

This was accomplished by clipping the low-frequency signal, thereby generating upper harmonics, and then selecting an appropriate upper harmonic by filtering. A prototype completed by Napoleon Lee was too large to justify taking it on the 1986 Africa trip, but smaller versions are now in the field for the 1987 work.

Figure 1

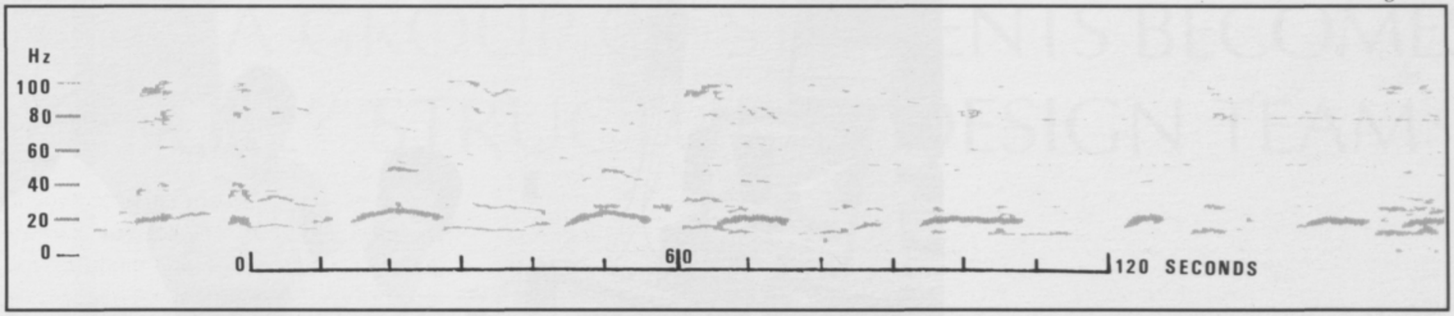


Figure 1. A sonogram of Asian elephant calls. African elephant calls are similar but not identical.

A DEVICE FOR BIRDWATCHERS WITH HIGH-FREQUENCY LOSS

In the fall of 1986, two additional spectral translation problems became M.Eng. design projects.

One project grew out of an interest I had in helping with an unusual hearing loss suffered by an acquaintance of mine. With ultra-audiometric hearing, as this condition is called, the person is totally deaf according to a hearing test as normally conducted, but there is some hearing in the high 5-to-15 kHz range. Sadly, human speech and other common sounds are virtually excluded by this loss (which is just the opposite of the normal aging loss).

The first frequency shifter I tried was never tested, partly because I met Lang Elliott, a photographer at the Laboratory of Ornithology, who offered insight in several areas. First, he knew of publications on ultra-audiometric hearing work: frequency shifting had been tried and found successful in part. He too had a personal interest in work of this kind because he has a *high-frequency* loss, similar to the aging loss but caused in his case by a youthful misadventure with a firecracker. In fact, he had acquired a frequency-shifter device that he was using to shift birdsongs down to a range, below 3 kHz, where he could hear them. He was not totally happy with the device, though, mostly because it inverted the song.

What seemed indicated was a device exactly the opposite of the "elephant detector." A simple subharmonic generator based on digital flip-flops was considered, and M.Eng. student Jon Jacobs took on the project. Elliott was quite pleased with the results, and now consideration is being given to making this sort of device available to the many birdwatchers who have experienced the normal aging loss. With the device, these people might again hear birdsongs they have long missed.

Figure 2

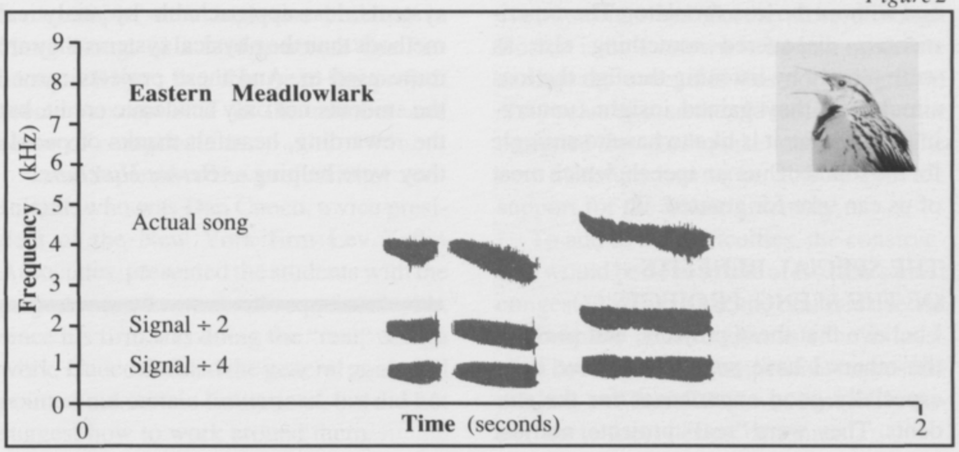
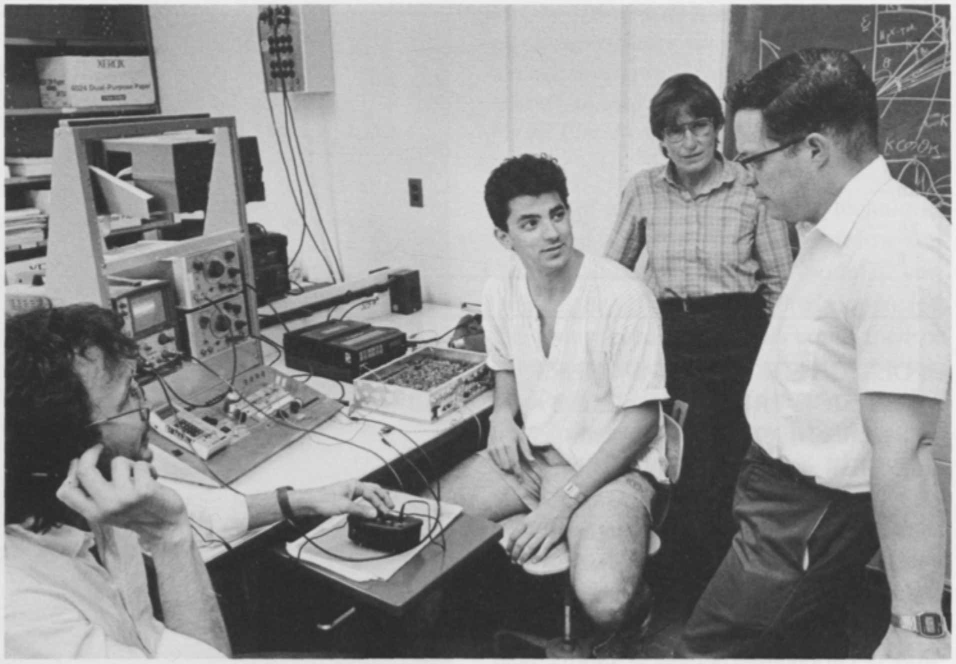


Figure 2. A sonogram of the eastern meadowlark's song shows how the frequency can be lowered to a level audible to people with high-frequency hearing loss. The actual signal is at 4–5 kHz, the signal divided by 2 is around 2 kHz, and the signal divided by 4 is near 1 kHz.

The frequency shifting is accomplished with a square-wave, flip-flop unit designed by M.Eng. student Jon Jacobs working with Bernie Hutchins. First the input signal is amplified. Then it is converted to a square wave for processing with a conventional flip-flop device, which can be programmed to divide the signal frequency by 2, 4, or even 3. Because amplitude variation is lost in the conversion to square wave, the amplitude envelope is isolated before the conversion step, and later used to amplitude-modulate the output signal. The divided frequency retains nearly all the essential qualities of the original input.



Bernie Hutchins (at right) confers with members of the elephant-call team: M.Eng. student Gregory Manganello (at center), and research associates Bill Langbauer and Katy Payne.

Hutchins is a teaching associate in the School of Electrical Engineering.

MAKING SPEECH AUDIBLE TO ULTRA-AUDIOMETRIC HEARERS

The ultra-audiometric project was not forgotten. A different approach, based on results that dated back to World War II research, was tried.

This work showed that "zero-crossed" speech is quite intelligible—that only a very tiny amount of the total information in a speech waveform is actually required for understanding. The human ear-brain system is an exceptionally powerful detector and processor of speech. The new approach was to take information from zero-crossing (essentially a time-domain process) and input it through a frequency channel that is accessible to the ultra-audiometric hearer.

M.Eng. student Pearl Lin was assigned the initial task of developing a hearing-loss simulator that would allow speech-translation devices to be tested on persons with normal hearing. Another student, Liliane Zreik, was given the problem of designing and constructing trial devices, using several suggested approaches.

The initial results are very promising in that persons with normal hearing are able to understand the extremely distorted speech coming out of the translators, with and without the loss simulator. The experimenters discovered something else as well: simply by listening through the loss simulators, they gained insight (unnerving) into what it is like to have to struggle for the sound of human speech, which most of us can take for granted.

THE SPECIAL BENEFITS OF THE M.ENG. PROJECTS

I believe that these projects, and some of the others I have supervised, have been especially good experiences for the students. They were "real" projects, not just makework. Often there were real deadlines to meet, and thought-provoking special circumstances to consider.

Beyond these benefits were some that were enriching in unexpected ways. These projects presented engineering students with an element of the unknown—an involvement with the behavior of living systems, less approachable by analytical methods than the physical systems they are more used to. And these projects earned the students not only academic credit, but the rewarding, heartfelt thanks of people they were helping.—*Bernie Hutchins*

HOW A GROUP OF STUDENTS BECOMES A "REAL" STRUCTURAL DESIGN TEAM

This year seventeen Cornell Master of Engineering students got together and designed a 33-story, $21-million office building. This was no ordinary class project: not only was the design for a real building in Boston, but the requirements were as complex as any practicing engineer is likely to see.

The students were taking a course in geotechnical and structural engineering design under the supervision of Professors Teoman Peköz, Fred Kulhawy, and Kenneth Hover. The course is noted for tough "real-world" assignments—the design of offshore platforms in the Gulf of Alaska, for example, or a high-rise building in Hong Kong, or a bridge across the Piscataqua River. But this year the project seemed exceptional in the number and scope of complications.

Last September the professional consultant, who was Dan Cuoco, a vice president of the New York firm Lev Zetlin Associates, presented the students with the project—one he was well acquainted with, since his firm was doing the "real" design work. Cuoco defined the general goals and pointed out certain limitations, but did not suggest how to work around them.

THE SPECIAL CHALLENGES OF A SPECIAL BUILDING

The first complication was that the new building was to be an L-shaped addition to a sixty-year-old structure. Eleven stories were to be connected and twenty-two would tower above the original structure. The new building had to be able to settle, as all new structures do, without disrupting the old building or cracking the connection between them.

The second major problem was that the unsymmetrical shape of the addition would make it susceptible to severe twisting under the stress of an earthquake or even a strong wind. Furthermore, although Boston is now known to be in a moderate earthquake zone, this was not recognized sixty years ago, so the old building was not designed for earthquake resistance. The new structure had to be able to provide support for the whole assembly.

To add to the difficulties, the construction would be done in one of Boston's most congested areas. Also, the builders needed to complete construction as soon as possible because of the competitive real estate market, and therefore it was especially important to meet design deadlines.

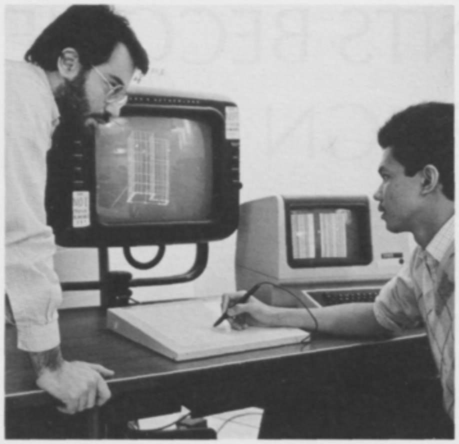
TEAM WORK FOR A PROFESSIONAL EFFORT

How did the students solve these problems? Basically, on their own. Functioning as a professional engineering firm, they broke up into teams, with each team assuming responsibility for a different aspect of the project. Although the professors and the consultant spent a great deal of time with the students, they did not tell them what to do. Cuoco never revealed his firm's "real" designs.

The student teams drafted a master plan by December. Completion of the design calculations, the drawings, and the model by the time of the formal presentation in February required concentrated effort, however. The intersession between academic terms became a marathon of work, all day, every day.

An international group, the students were not without special resources. Previous experiences were put to use. For example, Tateki Sakaguchi, who had been a field engineer with a Japanese construction firm for ten years, prepared a detailed drawing of the exterior to help the designers visualize the building as it would look upon completion.

1



1. In the design process, computer simulation was used to analyze the structure. These students are V. K. Mantzavinos (at left) and Carlos Antonio Reyes de Leon.

2. A highly accurate drawing of the proposed structure was prepared by M.Eng. student Tateki Sakagushi (at left) to help the design teams visualize the building.

3. The model ready for presentation is examined by Professor Peköz and students Maurice Zeiden and Amanda Hakim.

4. The design was presented at a formal session in February. This part of the presentation was made by Subhash Dhingra.

5. The "outisde" consultant, Dan Cuoco, was among those attending the presentation.

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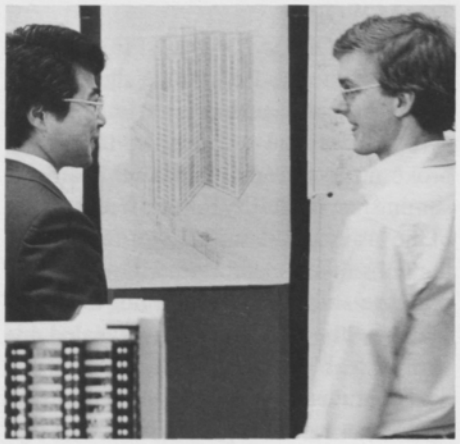

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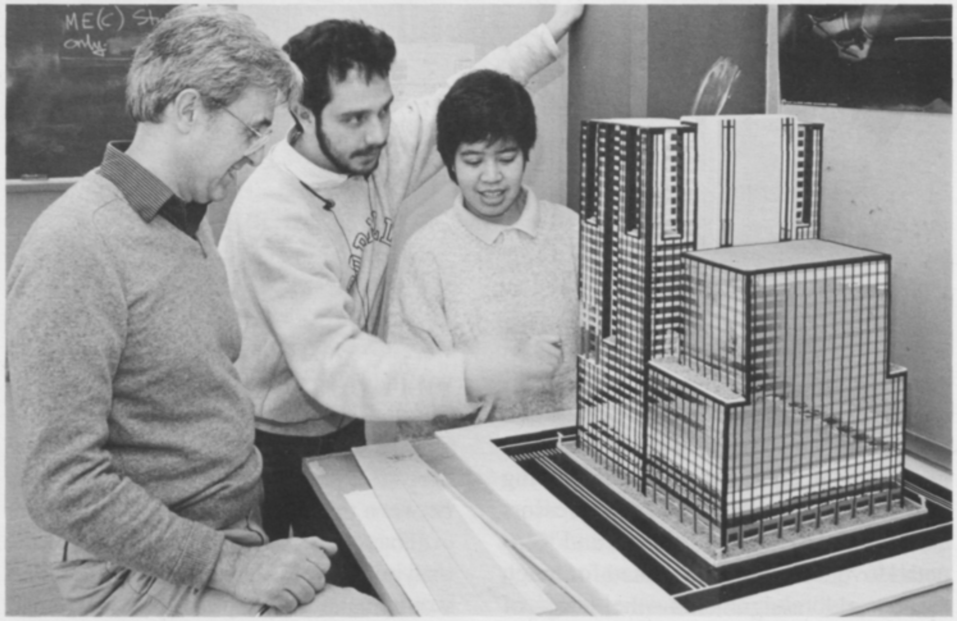

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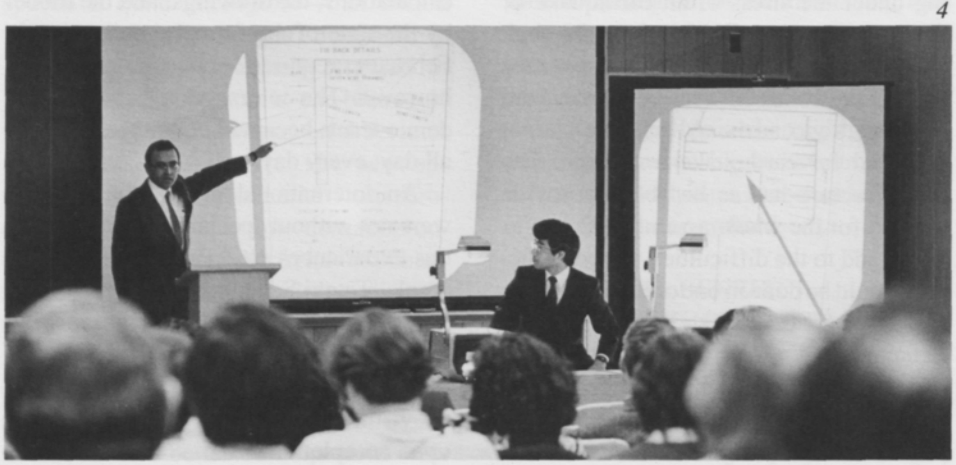


5

MAKING DESIGN DECISIONS AND CARRYING THEM OUT

The first step in the design process was to decide on the basic mode of construction. The team decided to use a concrete core throughout, with a steel frame above the eleventh floor and a concrete frame below. They decided on concrete for the lower part because of the need to match the ceiling-to-floor height in the old and new sections. Athough steel has the advantage of being lighter than concrete, and construction with steel is easier and faster, concrete allows for thinner floors and greater clearance.

To provide earthquake and wind resistance, the designers specified extra-strong columns and beams, and called for a post-tensioned floor system with embedded high-tension cables. The cables would work by providing compression, just as a person does in squeezing a row of books together to pick them up.

Although much design work is now done with computer simulation, Peköz forbade the use of high-tech tools in the initial phases of the project. He wanted the students to first develop reliance on intuition and reasoning. Finally, over intersession, the students were allowed to take advantage of Cornell's Computer-Aided Design Instructional Facility (CADIF), and they used computer simulation to analyze the structure for resistance to earthquakes and wind.

Again complications arose. Although a three-dimensional analysis would have given the best results, the amount and complexity of data would have exceeded the computer's memory capacity. The students compromised by using a simplified combination of 2-D and 3-D analysis, and by simulating the behavior of their 33-story building with a four-story model.

Innovations were used in connecting the two structures so as to allow the new one to settle without damaging the old one. Special bolts allowed sliding without cracking, and thin, flexible steel beams were specified.

The presence of surrounding buildings required careful shoring up of the excavation site, and even the composition of the earth was problematic. Boston lies on a soft layer of clay, glacial silt, and gravel, which requires a deep foundation to prevent too much settling. The question was, how deep? The geotechnical team members felt they needed more information than they had been given, and so requested a deeper exploratory boring, to a depth of 50 or 60 feet. On the basis of this second soil profile, they decided on a foundation with deep drilled shafts.

A HEAD START ON PROFESSIONAL CAREERS

The formal presentation of the design, along with discussion of the problems and their solutions, was given in February. Among those present was Dan Cuoco, who said he was greatly impressed with the students' work. Their designs were very close to what the professionals had produced: the same combination of concrete and steel construction, the same kind of foundation with drilled shafts, and a similar post-tensioned system.

Cuoco pointed out that this project provided the students with a big head start on their professional careers; many young engineers don't encounter work like this for years, he said. Even the experience of participating in a formal presentation—harder than it looks—is important.

The participants not only improve their professional skills, but get a leg up on job-hunting, Peköz remarked. For example, a consultant who worked with an earlier group of M.Eng. students was so impressed with their achievement that he began to seek graduates of the program as employees. A third of his staff now consists of Cornell Masters of Engineering.

But the greatest benefit of the course, according to Peköz, is the opportunity it gives students to work well, under pressure, as members of a team, and to communicate effectively. Strong friendships develop among students who work together so closely and for so long. The ties remain after graduation, and with an international group such as this year's class, the connections extend to many parts of the world, promoting understanding and cooperation among individuals and cultures.

How does the faculty find highly skilled consultants willing to spend valuable time, without pay, coaching students? Mainly, Peköz said, by coercing their friends. Dan Cuoco was "recruited" by Peköz.

Cuoco said he would be happy to come again, but next time he would like to do things a little differently: he would like to find a way to get the students started earlier on their design project. If this year's team had begun work a year and a half ago, he explained, perhaps their ideas could have been put to use in the actual design.

—Lindy Costello

USING CORNELL SOFTWARE TO ASSESS MANUFACTURING PRODUCTIVITY

When Cornell researchers develop computerized control techniques for improving industrial productivity, they need to test their mathematical models in practical situations.

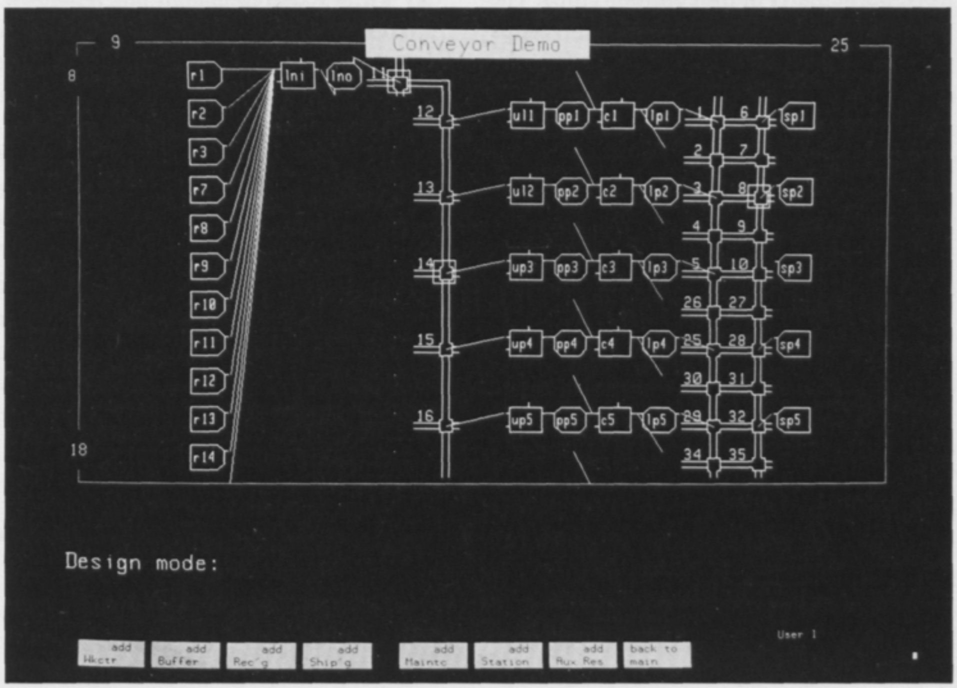
That is where Master of Engineering students come in. This year, for example, two M.Eng. students in operations research and industrial engineering used a Cornell-developed software system to analyze a production process at the IBM plant in Poughkeepsie, New York. Christopher J. Glynn and Firoozeh Mostashari worked closely with both their project adviser, Professor John A. Muckstadt, and IBM engineer Michael Isaac (a former doctoral student of Muckstadt's).

THE M.ENG. STUDY OF MODULE PRODUCTION AT IBM

The job assigned to the students was to use the simulation program COSMOS (Cornell Simulator of Manufacturing Operations) to analyze the efficiency of production of thermal conduction modules (TCMs) used in the 3090 family of mainframe computers, and to make recommendations for improvements in the manufacturing process. COSMOS, which was developed under the direction of Muckstadt and Professor Peter Jackson, is a set of models and software for evaluating the design and operation of multi-stage production systems.

The students began their project work

Above: M.Eng. students visited the IBM plant in Poughkeepsie in the course of their project work. Left to right are Professor John A. Muckstadt; students Christopher J. Glynn and Firoozeh Mostashari; Michael Isaac of IBM; and an unidentified production-line worker.



Left: Another M.Eng. (OR&IE) project this year was undertaken with the cooperation of engineers from General Motors. Three students worked on aspects of the same project, which was to design alternative operating methods for a plant that manufactures axles.

The photograph was taken during a visit to Cornell by the consultants. Left to right are William L. Maxwell, the Andrew Schultz, Jr. Professor of Industrial Engineering, who was the project adviser; D. Marshall Andrews of General Motors (seated); Neil A. Schilke of General Motors; and Lotfi Baccouche, one of the M.Eng. candidates.

The consultants are both Cornell graduates. Andrews, a member of the class of 1977, received the B.S. degree in operations research and industrial engineering. Schilke earned the B.M.E. in 1962 and the M.M.E. in 1964.

The other students who worked on the project are Anand Chandrasekher and John A. Muckstadt, Jr. (whose father is a member of the Cornell OR&IE faculty).

Left below: The consultation centered on the students' computer analyses of operating methods, using software developed at Cornell by Professors Maxwell and Richard W. Conway.

In the menu displayed on the screen the numbered boxes at left represent components used in the manufacture of different axle types. Selected items go to a conveyor system from which they are placed into lines preceding a welding operation. After the operation, they are placed into temporary storage, represented by the boxes on the right.

by studying the current process. At the IBM plant, different kinds of TCMs are built by assembling certain combinations of computer chips and ceramic substrates in a process called Bond/Assembly/Test (BAT). High-technology, computer-controlled tools place and connect conductive wires and chips on the multi-layer substrates. Each of these assemblies is encapsulated within a protective shield which is then filled with helium to facilitate the dissipation of heat by the module within the mainframe.

In an effort to increase productivity, IBM recently implemented a Continuous Flow Manufacturing (CFM) program which affected the BAT line by introducing techniques such as computerized control of materials and inventories during manufacture. Overall, CMF was successful. The time required for completion of a production cycle was decreased, inventories of work in process were reduced, and throughput was improved. As with the introduction of any new system, however, certain problems emerged. The chief one was a frequent shortage of the raw material—computer chips obtained from the IBM plant in East Fishkill, New York.

The students used COSMOS to build a model of the BAT line, and then they made a number of simulation runs to determine the effect of various factors. These included variability in the demand for completed units and in the delivery of the chips from the East Fishkill plant. Also, the requirements for adequate inventories of different kinds of chips were examined.

An analysis of the production data showed, for example, that most of the demand is for only a few of the TCM types that are manufactured. Further analysis showed that only a small number of chips are used in more than one type of TCM. Unavailability of any of these "common" chips is a more serious problem than the temporary lack of a "unique" chip.

The students recommended that despite the CMF policy of eliminating "buffer" stock inventory of raw materials, there should be some provision of an extra supply, particularly of the common chips. The BAT line should be buffered with chips rather than with finished modules, the report indicated, because "a small amount of chip inventory at the beginning of the production line provides more protection against variability than the same amount of finished modules at the end."

The best solution, the students' report suggested, lies somewhere between the extremes of zero buffer-stock inventory and the huge stockpiles that used to be common in American manufacturing. "A large amount of inventory is clearly wasteful," the report stated, "but zero inventory may not be optimal either. Small amounts of carefully positioned and monitored inventory will increase the efficiency of the manufacturing process and not tie up large amounts of capital in inventory."

Another recommendation was to modify the scheduling policy. Currently, modules are built according to the mix of types needed on a given day. Normally this is the correct BAT policy, but it does not cover backorders well. The report recommended a modified policy over the short term that would permit scheduling of some modules for production even if they do not meet that day's mix requirements.

Other aspects that might be assessed, the students' report suggested, are the scheduling of module repairs, the optimum accommodation of month-to-month variations in demand, and better integration of the BAT line with other areas of the Poughkeepsie facility.

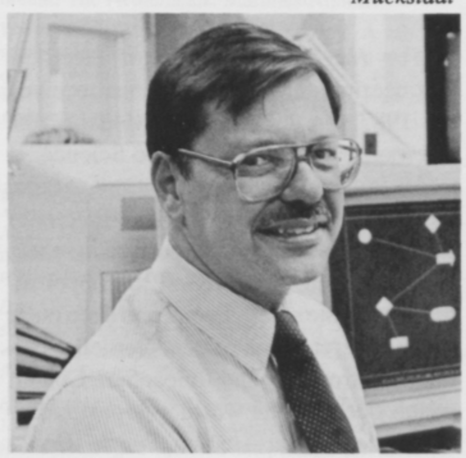
"At very little cost to the corporation," the report concluded, "COSMOS and other state-of-the-art modeling tools can provide insights that are necessary for efficient operation of Continuous Flow Manufacturing operations."

REGISTER

Hopcroft

Moon

Muckstadt



■ Newly appointed heads of academic units at the college are *John E. Hopcroft*, chairman of the Department of Computer Science; *Francis C. Moon,* director of the Sibley School of Mechanical and Aerospace Engineering; and *John A. Muckstadt,* director of the School of Operations Research and Industrial Engineering.

Hopcroft, who is the Joseph C. Ford Professor of Computer Science, has been on the Cornell faculty since 1967. He holds the Ph.D. from Stanford University and taught at Princeton University before coming to Cornell.

His honors include recent election to the American Academy of Arts and Sciences, and receipt of the Turing Award of the Association for Computing Machinery. Also, he is a fellow of the Institute of Electrical and Electronics Engineers and the American Association for the Advancement of Science. His specialty field is the design and analysis of algorithms and data structures. He has served on the National Research Council Computer and Technology Board, on a National Science Foundation advisory panel, as an editor of several professional journals, and as a consultant to several major corporations.

Moon, who has been chairman of the Department of Theoretical and Applied Mechanics since 1985, has worked on a wide range of problems in the dynamics of solids and structures. His most recent research is in chaotic dynamics and nonlinear vibrations in structures.

Moon earned the Ph.D. at Cornell in 1966 and taught in the Department of Aerospace and Mechanical Sciences at Princeton University before returning to Cornell as a faculty member in 1975. He has been a visiting engineer in the magnetic fusion division of Lawrence Livermore Laboratory, and is a consultant to the Argonne National Laboratory.

Muckstadt, a specialist in inventory and logistics control, was a founder of the Cornell Manufacturing Engineering and Productivity Program (COMEPP) and has served as its director.

He joined the Cornell faculty in 1974 after doctoral study at the University of Michigan, followed by twelve years as an officer in the Air Force. He has spent sabbatical leaves as a visiting professor at the Catholic University in Belgium. He has served as an editor of four professional journals and as an industrial consultant.

■ A former dean of the College of Engineering, *Thomas E. Everhart,* has been named president of the California Institute of Technology, effective in September. He is currently chancellor of the University of Illinois at Champaign-Urbana.

Everhart was engineering dean at Cornell from 1979 to 1984. Before that he was a professor and chairman of the Department of Electrical Engineering and Computer Science at the University of California at Berkeley. He is a specialist in electron optics and electron physics.

■ Another former dean of the college, *Dale R. Corson,* has been awarded the 1987 National Academy of Sciences Public Welfare Medal.

Corson, president emeritus of the university, came from the physics department to become dean of engineering in 1959. He became the university's provost in 1963, and president in 1969.

His recent activities on the national level include heading a study sponsored by the National Academy of Sciences that dealt with the concern of universities about the "gray " area of research that is not classified but is considered militarily useful. The report was published in 1982.

■ *Tor Hagfors,* professor of electrical engineering and astronomy, has received the 1987 van der Pol Gold Medal of the International Union for Radio Science.

He is cited for his contributions to radar engineering and for his work as director of some of the world's largest radio-radar facilities used for studying the upper atmosphere, the solar system, and deep outer space. Currently he directs Cornell's National Astronomy and Ionosphere Center, which operates the world's largest radio-radar telescope at Arecibo, Puerto Rico.

Isacks

■ Sixteen years after its publication, a paper by a Cornell engineering professor has brought him the 1986 Outstanding Publication Award of the Association of Environmental Engineering Professors.

The paper by *Richard I. Dick,* who is the Joseph P. Ripley Professor of Engineering in Cornell's School of Civil and Environmental Engineering, was selected for having had a significant and lasting impact on the discipline. His specialty field is water and wastewater treatment.

■ The High Distinction of *Honoris Causa* has been awarded by the Ecole Centrale de Lyon to *John L. Lumley,* the Willis H. Carrier Professor of Engineering in Cornell's Sibley School of Mechanical and Aerospace Engineering.

Cornell was represented at the ceremony, held July 9 in Lyon, by William B. Streett, dean of the College of Engineering, and Alison Casarett, dean of the Graduate School.

Lumley was instrumental in developing a graduate exchange program between Cornell and the Ecole Centrale de Lyon. He was a Guggenheim fellow at Lyon and at the university in Aix-Marseille in 1973.

■ *Bryan L. Isacks* has been named Cornell's first William and Katherine Snee Professor of Geological Sciences. A specialist in seismology and tectonics, he has been on the faculty here since 1971.

The new chair was endowed by Katherine Snee and the late William Snee '25, for whom the recently constructed geological sciences building on the engineering campus is named.

Isacks came to Cornell at the time the Department of Geological Sciences was being reorganized as a unit of the College of Engineering as well as the College of Arts and Sciences. The revitalization of the department was largely in response to the emergence of plate tectonics as an important unifying concept in the discipline. Isacks is an author of more than seventy papers, including one on global tectonics that is regarded as a classic.

Isacks studied at Columbia University, which awarded him the Ph.D. in 1958. Subsequently he conducted research at Columbia's Lamont-Doherty Geological Observatory.

He is a fellow of both the American Geophysical Union and the Geological Society of America. He has served on the board of directors of the Seismological Society of America and is currently chairman of the Geophysics Division of the Geological Society of America.

■ *William McGuire,* professor of structural engineering, has received Buckell University's 1987 Alumni Award for Distinguished Service. The award was made "in recognition of meritorious achievement in a chosen profession."

McGuire was graduated from Bucknell in 1942 with a B.S. degree, magna cum laude, in civil engineering. He did graduate work at Cornell.

FACULTY PUBLICATIONS

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 December 1986 through March 1987. (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 ENGINEERING

Etheridge, S. P., and *W. J. Jewell*. 1987. Anaerobic decomposition of solids. Paper read at International Congress and Exhibition for Bioengineering, 17–19 March 1987, in Dusseldorf, Germany.

Gebremedhin, K. G. 1986. A structures analyzer program for wood systems on microcomputers. In *Proceedings, 4th National Conference on Microcomputers in Civil Engineering*, ed. W. E. Carroll, pp. 212–15. New York: American Society of Civil Engineers.

Gebremedhin, K. G., E. L. Bahler, and S. R. Humphreys. 1986. A modified approach to post-frame design using diaphragm theory. *Transactions of the American Society of Agricultural Engineers* 29(5):1364–72.

Haith, D. A., and *D. E. Merrill*. 1987. Evaluation of a daily rainfall erosivity model. *Transactions of the American Society of Agricultural Engineers* 30(1):90–93.

Hillman, P. E., *K. G. Gebremedhin*, and *R. G. Warner*. 1986. Calf nursery ventilation control: Ammonia and air flow patterns. Paper no. 86–4549 read at American Society of Agricultural Engineers Winter Meeting, 16–19 December 1986, in Chicago, IL.

Jewell, W. J. 1987. Anaerobic sewage treatment. *Environmental Science and Technology* 21:14–21.

Kaufman, S. S., and *D. A. Haith*. 1986. Probabilistic analysis of sludge land application. *Journal of Environmental Engineering* 112(6):1041–53.

Rehkugler, G. E. 1987. Engineering mechanical, electrical, and energy systems to serve agriculture. *New York's Food and Life Sciences Quarterly* 17(2):32-33.

Rehkugler, G. E. 1987. Field definition: Agricultural engineering. In *Accounting to zoology: Graduate fields defined*, ed. A. J. Goldstein, p. 320. Princeton, NJ: Peterson's Guides.

Rehkugler, G. E., and *W. W. Gunkel*. 1987. Department of Agricultural Engineering. In *One hundred years of agricultural research at Cornell University: A celebration of the centennial of the Hatch Act, 1887–1987*, pp. 8–13. Ithaca, NY: Cornell University.

Rehkugler, G. E., and *N. C. Rehkugler*. 1986. Marketing agricultural engineering: Profession, education, careers. Paper read at American Society of Agricultural Engineers Winter Meeting, 15–19 December 1986, in Chicago, IL.

■ APPLIED AND ENGINEERING PHYSICS

French, R. G., and *R. V. E. Lovelace*. 1987. Strong turbulence and atmospheric waves in stellar occulations. *Icarus* 56:122-46.

Isaacson, M., *E. Betzig*, *A. Harootunian*, and *A. Lewis*. 1986. Scanning optical microscopy at $\lambda/10$ resolution using near-field imaging methods. In *Recent advances in electron and light optical imaging in biology and medicine*, ed. A. P. Somlyo, pp. 448–58. New York: New York Academy of Sciences.

Kratschmer, E., and *M. Isaacson*. 1987. Progress in self-developing fluoride resists. *Journal of Vacuum Science and Technology B* 5:369–73.

Lee, K., *J. Silcox*, and *C. A. Lee*. 1986. Schottky barrier diode on a submicron thick silicon membrane using a dual surface fabrication technique. *Journal of Applied Physics* 60:4038–40.

Lovelace, R. V. E. 1987. Astron disc equilibria. *Plasma Physics* 22:977–90.

Lovelace, R. V. E., and *C. B. Ruchti*. (1983.) Electron/positron/gamma ray beams in cosmic radio sources. In *Proceedings, Workshop on e± pairs in astrophysics*, pp. 14–331. New York: American Institute of Physics.

Lovelace, R. V. E., *D. G. Stout*, and *P. L. Steponkus*. 1987. Protoplast rotation in a rotating electric field: The influence of cold acclimation. *Journal of Membrane Biology* 82:157–66.

Pao, Y.-H. 1987. Theory of acoustoelasticity and acoustoplasticity. In *Solid mechanics research for quantitative non-destructive evaluation*, ed. J. D. Achenback and Y. Rajapaske, pp. 257–73. Dordrecht, The Netherlands: Martinus Nijhoff.

Webb, W. W. 1987. Light microscopy: A modern renaissance. In *Recent advances in electron and light optical imaging in biology and medicine*, ed. A. P. Somlyo, vol. 483, pp. 387–91. New York: New York Academy of Sciences.

■ CHEMICAL ENGINEERING

Ataai, M. M., and *M. L. Shuler*. 1987. Mathematical model for the control of ColE1 type plasmid replication. *Plasmid* 16:204–12.

Das, S., and *F. Rodriguez*. (1986.) The kinetics of solution copolymerization of vinyl chloroacetate with vinyl acetate in a CSTR. *Journal of Applied Polymer Science* 32:5981–99.

Eggebrecht, J., *K. E. Gubbins*, and *S. M. Thompson*. 1987. The liquid-vapor interface of simple polar fluids. 1. Integral equation and perturbation theories.

2. Computer simulation. *Journal of Chemical Physics* 86:2286–2308.

Georgiou, G., M. L. Shuler, and *D. B. Wilson.* 1987. Effects of high level protein synthesis on excretion and processing of β-lactamase. Paper read at annual meeting, American Society for Microbiology, 1–6 March 1987, in Atlanta, GA.

Georgiou, G., D. B. Wilson, and *M. L. Shuler.* (1986.) Effects of alkaline pH on the production of β-lactamase in *E. coli.* Paper read at meeting, American Chemical Society, 30 August–4 September 1986, in New Orleans, LA.

Gold, T., B. E. Gordon, *W. Streett, E. Bilson,* and *P. Patnaik.* 1986. Experimental study of the reaction of methane with petroleum hydrocarbons in geological conditions. *Geochimica et Cosmochimica Acta* 50:2411-18.

Koch, D. L., and J. F. Brady. 1987. The symmetry properties of the effective diffusivity tensor in anisotropic porous media. *Physics of Fluids* 30:642–50.

Rodriguez, F., L. J. Mathias, J. Kroschwitz, and C. E. Carraher, Jr. 1987. Classroom demonstrations of polymer principles. 1. Molecular structure and molecular mass. *Journal of Chemical Education* 64:72–76.

Shuler, M. L., and *G. A. Hallsby.* 1986. Bioreactor considerations for chemical production from plant cell cultures. In *Biotechnology in plant science: Relevance to agriculture in the nineteen eighties,* ed. M. Zaitlin, P. Day, and A. Hollaender, pp. 191–205. Orlando, FL: Academic.

Wei, G., and *C. Cohen.* 1986. Direct method of calculating the dynamic scattering spectrum. *Journal of Polymer Science B* 24:2703–24.

■ CIVIL AND ENVIRONMENTAL ENGINEERING

Arita, M., G. H. Jirka, and N. Tamai. 1986. Classification and mixing of two-dimensional buoyant surface discharges. *Journal of Hydraulic Research* 25(5): 333–45.

Brutsaert, W. 1987. Recent developments in watershed evaporation. Paper read at U.S.–Japan Seminar on Hydrology, 5–9 January 1987, in Honolulu, HI.

Brutsaert, W., and *W. P. Kustas.* 1987. Surface water vapor and momentum fluxes under unstable conditions from a rugged-complex area. *Journal of the Atmospheric Sciences* 44:421–31.

Chu, V. H., and *G. H. Jirka.* 1986. Buoyant surface jets and plumes in environmental fluid mechanics. In *Encyclopedia of fluid mechanics,* ed. N. Cheremisinoff, pp. 1053–84. Houston, TX: Gulf.

Dick, R. I. 1987. Review of *A mathematical model of settling velocity enhancement by kinetic control,* by C. B. Schnelle, Jr., K. D. Schnelle, S. J. Gibbs, and D. J. Wilson. *Environmental Progress* 6:F5.

Garbarini, D. R., and *L. W. Lion.* 1987. Influence of the nature of soil organics on the sorption of toluene and trichloroethylene. *Environmental Science and Technology* 20(12):1263–69.

Gordon, D. K., W. R. Philipson, and *W. D. Philpot.* 1986. Fruit tree inventory with Landsat Thematic Mapper data. *Photogrammetric Engineering and Remote Sensing* 52:1871–76.

Holley, E. R., and *G. H. Jirka.* 1986. *Mixing and solute transport in rivers.* U.S. Army Corps of Engineers, Waterways Experiment Station report no. E-86–11. Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station.

Ingraffea, A. R., and *C. Mink.* 1987. Why Cornell engineers have up-to-date design skills. *Engineering: Cornell Quarterly* 21(2):18–24.

Jirka, G. H., and *M. Arita.* 1987. Density currents or density wedges: Boundary layer influence and control methods. *Journal of Fluid Mechanics* 177:186–206.

Jirka, G. H., J. M. Colonell, and D. Jones. 1986. Outfall mixing design in shallow water under arctic ice cover. *Journal of the Marine Technology Society* 20(6):44–53.

Jones, J. M., and *G. H. Jirka.* (1985.) Steady two-dimensional density current dynamics. Paper read at International Symposium on Refined Modeling and Turbulence Measurements, 16–18 September 1985, in Iowa City, IA.

Kustas, W. P., and *W. Brutsaert.* 1986. Regional estimates of evaporation over a rugged-complex area using radiosonde data. *EOS* 67:961.

———.1987. Virtual heat entrainment in the mixed layer over very rough terrain. *Boundary-Layer Meteorology* 38:141–57.

Lawler, D. R., and *R. I. Dick.* 1987. Review of *Unified analysis of thickening,* by D. E. Baskin and M. T. Suidan. *Journal of Environmental Engineering* 113:215–16.

Liu, P. L.-F. 1987. Effects of depth discontinuity on the harbor oscillations. *Journal of Coastal Engineering* 10:395–404.

Orloff, N. 1987*a*. *Proposition 65.* Chicago, IL: American Bar Association.

———. 1987*b*. Risk assessment: Fact and fiction. *University of Southern California Journal of Law and the Environment* 3:1–16.

———. 1987*c*. Theories of cancer and rules of causation jurimetrics. *Journal of Law, Science and Technology* 27(3):255–62.

Pei, D., S. J. Burges, and *J. R. Stedinger.* 1987. Seasonal runoff volume forecasts conditioned on a total runoff forecast. *Water Resources Research* 23(1):9–14.

Richardson, A. J. 1987. Sampling methods and sample size theory. Paper read at 66th Annual Meeting of the Transportation Research Board, 12–15 January 1987, in Washington, DC.

Sherman, R. E., S. P. Glass, and *L. W. Lion.* 1987. A comparison of toxicity tests conducted in the laboratory and in experimental ponds using cadmium and the fathead minnow *Pimephales promelas. Water Research* 21(3):317–23.

Stedinger, J. R., and V. R. Baker. 1987. Surface water hydrology: Historical and paleoflood information. *Reviews of Geophysics and Space Physics* 25(3): 119–24.

Strycharczyk, J. B, and *J. R. Stedinger.* 1987. Evaluation of the "Reliability Programming" reservoir model. *Water Resources Research* 23(2):225–29.

Trautmann, C. H. (1986.) Seismic risk to water and sewage lifeline systems. In *Proceedings, Workshop on Abatement of Seismic Hazards to Lifelines.* Washington, DC: Building Seismic Safety Council.

Turnquist, M. A. 1987. Routes, schedules and risks in transporting hazardous materials. In *Strategic planning in energy and natural resources,* ed. B. Lev, pp. 289–302. Amsterdam, The Netherlands: North-Holland.

Vodacek, A., and *W. D. Philpot.* 1987. Environmental effects on laser-induced fluorescence spectra of natural waters. *Remote Sensing of Environment* 53:187–91.

Vogel, R. M., and *J. R. Stedinger.* 1987. Generalized storage–reliability–yield relationships. *Journal of Hydrology* 89(3/4):303–27.

White, R. N., and *P. Gergely,* eds. 1986. *Seismic performance of existing buildings: Proceedings, 3d (1985) Workshop.* Ithaca, NY: Cornell University.

Williams, V. L., W. R. Philipson, and *W. D. Philpot.* 1987. Indentifying vegetable crops with Landsat Thematic Mapper data. *Photogrammetric Engineering and Remote Sensing* 21:83–95.

Zhou, C., and *P. L.-F. Liu.* 1987. Sceond-order low frequency wave forces on a vertical circular cylinder. *Journal of Fluid Mechanics* 175:143–55.

■ COMPUTER SCIENCE

Birman, K. P., and *T. A. Joseph.* 1987. Reliable communication in the presence of failures. *ACM Transactions on Computer Systems* 5(1):47–76.

Feijen, W., N. van Gasteren, and *D. Gries.* 1987. In-situ inversion of a cyclic permutation. *Information Processing Letters* 24:11–14.

Hartmanis, J. 1987. The structural complexity column: A retrospective on structural complexity. In *Bulletin of the European Association for Theoretical Computer Science,* ed. G. Rozenberg, pp. 115–22. Leiden, The Netherlands: EATCS.

Salton, G., and Y. Zhang. Enhancements of text representations using related document titles. *Information Processing and Management* 22(5):385–94.

Widom, J., D. Gries, and *F. B. Schneider.* 1987. Completeness and incompleteness of trace-based network proof systems. In *Proceedings, 14th Annual ACM SIGACT–SIGPLAN Symposium on Principles of Programming Languages,* pp. 27–38. New York: Association for Computing Machinery.

■ ELECTRICAL ENGINEERING

Anantharam, V., and P. Varaiya. 1986. New results on multiarmed bandit problems. In *Proceedings, 25th Institute of Electrical and Electronics Engineers Conference on Decision and Control.* New York: IEEE.

Chen, M., W. J. Schaff, P. J. Tasker, and *L. F. Eastman.* 1987. Self-aligned GaAs gate heterojunction SISFET. *Electronic Letters* 23:105–06.

Chen, X., and *T. W. Parks.* 1987. Design of FIR filters in the complex domain. *IEEE Transactions on Acoustics, Speech, and Signal Processing* 35:144–53.

Chen, Y.-K., D. C. Radulescu, F. E. Najjar, P. J. Tasker, G. W. Wicks, and *L. F. Eastman.* 1987. High frequency instability in a double-heterojunction power MODFET. Paper read at WOCSEMMAD, 2–4 March 1987, in Hilton Head, SC.

Chiang, H. D., F. F. Wu, and P. P. Varaiya. 1987. Foundations of direct methods for power system transient stability analysis. *IEEE Transactions on Circuits and Systems* 34:160–73.

Eastman, L. 1986*a*. Materials structures for high electron transit velocity in MODFETs. Paper read at Conference on Selectively Doped Heterostructure Transistors, 1–6 December 1986, in Keauhou-Kona, HI.

———. 1986*b*. III-V heterojunction field effect transistor using indium alloys. Paper read at International Electronics Devices Meeting, 7–10 December 1986, in Los Angeles, CA.

Eastman, L. F. 1987*a*. *Electron ballistic injection and extraction for very high efficiency, high frequency transferred electron devices.* U.S. patent no. 4,649,405, 10 March 1987.

———. 1987*b*. High speed electrons for faster transistors. Paper read at Workshop on Ballistic Electrons for Transistors, 22–27 March 1987, in Santa Barbara, CA.

Farley, D. T., E. Bonelli, B. G. Fejer, and M. F. Larsen. 1986. The prereversal enhancement of the zonal electric field in the equatorial ionosphere. *Journal of Geophysical Research* 91:13,723–28.

Fejer, B. G., J. Providakes, D. T. Farley, and *W. E. Swartz.* 1986. Auroral E region plasma waves and elevated electron temperatures. *Journal of Geophysical Research* 91:13,583–92.

Feketa, D., K. T. Chan, J. M. Ballantyne, and *L. F. Eastman.* 1986. Graded-index separate-confinement InGaAs/GaAs strained-layer quantum well laser grown by metalorganic chemical vapor deposition. *Applied Physics Letters* 49:1659–60.

Fekete, D., D. Bour, J. M. Ballantyne, and *L. F. Eastman.* 1987. GaAs/GaAlAs quantum well laser with a lateral spatial variation in thickness grown by metalorganic chemical vapor deposition. *Applied Physics Letters* 50:635–37.

Foisy, M. C., J. C. Huang, *P. J. Tasker,* and *L. F. Eastman.* 1987. Modulation efficiency limited high frequency performance of the MODFET. Paper read at 2nd meeting, Picosecond Electronics and Optoelectronics, 14–16 January 1987, in Reno, NV.

Greenwald, Z., D. W. Woodard, A. R. Calawa, *L. F. Eastman, A. Al Omar,* and *J. P. Krusius.* 1987. Electron injection from energy stepped cathodes in mm-wave gun oscillators. Paper read at Workshop on Ballistic Electrons for Transistors, 22–27 March 1987, in Santa Barbara, CA.

Hagfors, T. 1987. Improved sensitivity for future pulsar observations at Arecibo Observatory. Paper read at meeting, Union Radio Scientifique Internationale (URSI), 12–16 January 1987, in Boulder, CO.

Heegard, C. 1987. Properties of constrained modulation codes. Paper read at National Radio Science Meeting, 12–15 January 1987, in Boulder, CO.

Hoch, H. C., R. C. Staples, B. Whitehead, J. Comeau, and *E. D. Wolf.* 1987. Signaling for growth orientation and cell differentiation by surface topography in *Uromyces. Science* 235:1659–62.

Isham, B., W. Birkmayer, T. Hagfors, W. Korman, C. La Hoz, and B. Thidé. 1987. The implementation of the Chirp technique for plasma line observations at EISCAT. Paper read at 3rd International Workshop, European Incoherent Scattering Association, 23–27 March 1987, in Bad Lauterberg, Germany.

Jennings, D. A., R. E. Drullinger, K. M. Evenson, *C. R. Pollock,* and J. S. Wells. 1987. The continuity of the meter: The redefinition of the meter and the speed of visible light. *Journal of Research of the National Bureau of Standards* 92:11–16.

Lepore, A., D. Radulescu, W. J. Schaff, P. J. Tasker, and *L. F. Eastman.* 1986. Short channel effects in sub-micron self-aligned-gate AlGaAs/GaAs digital MODFETs. Paper read at Conference on Selectively Doped Heterostructure Transistors, 1–6 December 1986, in Keauhou-Kona, HI.

———. 1987. Self-aligned-gate digital AlGaAs/GaAs modulation-doped field effect transistor (MODFET) processing and short channel effects. Paper read at meeting, Society of Photo-Optical Instrumentation Engineers (SPIE), 23–27 March 1987, in Bay Point, FL.

Linke, S. ed. 1987. *Computers: Proceedings, Cornell Electrical Engineering Centennial Symposium at East Windsor, NJ.* Future Directions in Electrical Engineering, pt. 2. Ithaca, NY: Promethean.

Mareels, I. M. Y., R. R. Bitmead, M. Gevers, *C. R. Johnson, Jr.,* R. L. Koust, and M. A. Poubelle. 1987. How exciting can a signal really be? *Systems and Control Letters* 8:197–204.

Mitsunaga, M., and *C. L. Tang.* 1987. Theory of quantum beats in optical transmission-correlation and pump-probe measurements. *Physics Review A* 35:1720–28.

Najjar, F. E., D. C. Radulescu, Y.-K. Chen, G. W. Wicks, P. J. Tasker, and *L. F. Eastman.* 1987. Characterization of GaAs/AlAs tunnelling emitter bipolar transistors. Paper read at WOCSEMMAD, 2–4 March 1987, in Hilton Head, SC.

Palmateer, L. F., P. J. Tasker, T. Itoh, A. S. Brown, G. W. Wicks, and *L. F. Eastman.* 1987. Microwave characterisation of 1 micron-gate $Al_{0.48}In_{0.52}As$/$Ga_{0.47}In_{0.53}As$/InP MODFETs. *Electronic Letters* 23:53–55.

Radulescu, D. C., G. W. Wicks, W. J. Schaff, A. R. Calawa, and *L. F. Eastman.* 1987. Anisotropic transport in modulation-doped quantum-well structures. *Journal of Applied Physics* 61:2301–06.

Ralph, S. E., and *G. J. Wolga.* 1987. Study of hot electron transport in GaAs by quasi-elastic light scattering. Paper read at Conference on Ballistic Electrons for Transistors, 22–27 March 1987, in Santa Barbara, CA.

Ramberg, L. P., P. M. Enquist, Y.-K. Chen, F. E. Najjar, L. F. Eastman, E. A. Fitzgerald, and *K. L. Kavanaugh.* 1987. Lattice-strained heterojunction InGaAs/GaAs bipolar structures: Recombination properties and device performance. *Journal of Applied Physics* 61:1234–36.

Rosker, M. J., F. W. Wise, and *C. L. Tang.* 1986. Femtosecond optical measurement of hot-carrier relaxation in GaAs, AlGaAs, and GaAs/AlGaAi multiple quantum wells. *Applied Physics Letters* 49:1726–28.

Schaff, W. J., L. F. Palmateer, L. D. Nguyen, A. N. Lepore, M. C. Foisy, P. J. Tasker, and *L. F. Eastman.* 1986. AlGaAs/GaInAs/GaAs material characterization and pseudomorphic quantum well MODFETs. Paper read at Conference on Selectively Doped Heterostructure Transistors, 1–6 December 1986, in Keauhou-Kona, HI.

Tang, C. L. 1987. Femtosecond studies of ultrafast relaxation dynamics of hot carriers in GaAs and related compounds. Paper read at Conference on Ballistic Electrons for Transistors, 22–24 March 1987, in Santa Barbara, CA.

Tasker, P. J., and *L. F. Eastman.* 1987. The correct determination of intrinsic f_T of FET devices from measured microwave data. Paper read at WOCSEMMAD, 2–4 March 1987, in Hilton Head, SC.

Wise, F. W., M. J. Rosker, and *C. L. Tang.* 1987. Oscillatory femtosecond relaxation of photoexcited organic molecules. *Journal of Chemical Physics* 86:2827–32.

Wong, S. S., D. C. Chen, P. Merchant, T. R. Cass, J. Amano, and K. Y. Chin. 1987. HPSAC: A silicided amorphous-silicon contact and interconnect technology for VLSI. *IEEE Transactions on Electron Devices* 34:587–92.

■ GEOLOGICAL SCIENCES

Allmendinger, R. W., T. A. Hauge, E. C. Hauser, C. J. Potter, S. L. Klemperer, K. D. Nelson, P. Kneupfer, and *J. Oliver.* 1987. Overview of the COCORP 40°N transect, western United States: The fabric of an orogenic belt. *Geological Society of America Bulletin* 98:308–19.

Bassett, W. A. (1986.) John C. Jamieson, pioneer in experimental mineralogy. *Journal of Geophysical Research* 91:4621–24.

Bassett, W. A., and *M. S. Weathers.* (1986.) Temperature measurement in laser heated diamond anvil cells. *Physica B* 139, 140:900–02.

Bloom, A. L. 1986. Coastal landforms. In *Geomorphology from space,* ed. N. M. Short and R. W. Blair, Jr., pp. 353–406. Washington, DC: National Aeronautics and Space Administration.

Brown, L., D. Willie, L. Zhang, B. deVoogd, J. Mayer, T. Hearn, W. Sanford, C. Caruso, T.-F. Zhu, K. D. Nelson, C. Potter, E. Hauser, S. Klemperer, S. Kaufman, and *J. Oliver.* 1987. COCORP: New perspectives on the deep crust. *Geophysical Journal of the Royal Astronomical Society* 89:47–53.

Cathles, L. M. (1986.) The geologic solubility of gold from 200–350°C, and its implications for gold-base metal ratios in vein and stratiform deposits. In *Gold in the western shield,* ed. L. A. Clark, vol. 38, pp. 187–210. Montreal: Canadian Institute of Mining and Metallurgy.

Debar, S., S. Mahlburg Kay, and *R. W. Kay.* 1987. Ultramafic xenoliths from Adagdak Volcano, Adak, Aleutian Islands, Alaska: Deformed igneous cumulates from the Moho of an island arc. *Journal of Geology* 95:329–41.

Hauge, T. A., R. W. Allmendinger, C. Caruso, E. C. Hauser, S. L. Klemperer, S. Opdyke, C. Potter, W. Sanford, L. Brown, S. Kaufman, and *J. Oliver.* 1987. Crustal structure of western Nevada from COCORP deep seismic-reflection data. *Geological Society of America Bulletin* 98:320–29.

Huang, E., and *W. A. Bassett.* (1986.) Rapid determination of Fe_3O_4 phase diagram by synchrotron radiation. *Journal of Geophysical Research* 91: 4697–4703.

Johnson, N. M., *T. E. Jordan,* P. A. Johnson, and C. W. Naeser. 1986. Magnetic polarity stratigraphy, age and tectonic setting of fluvial sediments in the eastern Andean foreland basin, San Juan province, Argentina. In *Foreland basins,* ed. P. A. Allen and P. Homewood, pp. 63–75. Oxford, England: Blackwell Scientific.

Jordan, T. E., and *R. W. Allmendinger.* 1986. The Sierras Pampeanas of Argentina: A modern analogue of Rocky Mountain foreland deformation. *American Journal of Science* 286:737–64.

Jordan, T. E., and R. N. Alonso. 1987. Cenozoic stratigraphy and basin tectonics of the Andes Mountains, 20–28° south latitude. *American Association of Petroleum Geologists* 71:49–64.

Karig, D. E. 1987. Review of *Distribution of maximum burial temperatures across northern Appalachian Basin and implications for Carboniferous sedimentation patterns,* by M. J. Johnson. *Geology* 15:278–79.

Karig, D. E., A. J. Barber, T. Charlton, and *S. Klemperer.* 1987. Nature and distribution of deformation across the Banda Arc–Australian collision zone at Timor. *Geological Society of America Bulletin* 98:18–32.

Kellog, L. H., and *D. L. Turcotte.* 1987. Homogenization of the mantle by convective mixing and diffusion. *Earth and Planetary Science Letters* 81:371–78.

Klemperer, S. L. 1987. Seismic noise-reduction techniques for use with vertical stacking: An empirical comparison. *Geophysics* 10:322–34.

Liu, L., and *W. A. Bassett.* (1986.) *Elements, oxides, silicates.* New York: Oxford University Press.

Mahlburg Kay, S., and B. Foster. (1986.) Kimberlites of the Finger Lakes region. In *New York State Geological Association field trip guidebook,* ed. *J. L. Cisne,* pp. 219–38. Ithaca, NY: New York State Geological Association.

McBride, J., and *L. D. Brown.* 1986. Reanalysis of the COCORP deep seismic reflection profile across the San Andreas fault, Parkfield, California. *Bulletin of the Seismological Society of America* 76:1668–86.

Nelson, K. D., J. H. McBride, J. A. Arnow, D. M. Wille, L. D. Brown, J. E. Oliver, and *S. Kaufman.* 1987. Results of recent COCORP profiling in the southeastern United States. *Geophysical Journal of the Royal Astronomical Society* 89:141-46.

Potter, C. J., R. W. Allmendinger, E. C. Hauser, and *J. E. Oliver.* 1987. COCORP deep seismic reflection traverses of the U.S. Cordillera. *Geophysical Journal of the Royal Astronomical Society* 89:99-104.

Potter, C. J., C.-S. Liu, J. Huang, L. Zheng, T. A. Hauge, E. C. Hauser, R. Allmendinger, J. Oliver, S. Kaufman, and *L. Brown.* 1987. Crustal structure of north-central Nevada: Results from COCORP deep seismic profiling. *Geological Society of America Bulletin* 98:330–37.

Potter, C., W. Sanford, T. Yoos, E. Prussen, R. W. Keach, J. Oliver, S. Kaufman, and *L. Brown.* 1986. COCORP deep seismic reflection traverse of the interior of the North American Cordillera, Washington and Idaho: Implications for orogenic evolution. *Tectonics* 5:1007–25.

Saleeby, J. B., R. C. Speed, M. Blake, *R. W. Allmendinger,* et al. 1986. *C-2 central California offshore to Colorado Plateau.* Geological Society of America Centennial Continent–Ocean Transect, special publication no. 10. Boulder, CO: GSA.

Sarewitz, D. R., and *D. Karig.* 1986. Stratigraphic framework of Mindoro Island, Philippines. *The Philippine Geologist* 40:3–51.

Spence, D. A., P. W. Sharp, and *D. L. Turcotte.* 1987. Buoyancy-driven crack propagation: A mechanism for magma migration. *Journal of Fluid Mechanics* 174:135–53.

Strecker, M. S., A. L. Bloom, L. M. Gilpin, and F. W. Taylor, Jr. 1986. Karst morphology of uplifted quaternary coral limestone terraces: Santo Island, Vanuatu. *Zeitschrift für Geomorphologie* 30(4):387–405.

Turcotte, D. L. 1986*a*. A fractal model for crustal deformation. *Tectonophysics* 132:261-69.

———. 1986*b*. Properties of the lithosphere and asthenosphere deduced from geoid observations. In *Space geodesy and geodynamics,* ed. A. J. Anderson and A. Cazenave, pp. 451–75. London: Academic.

———. 1987*a*. A fractal interpretation of topography and geoid spectra on the Earth, Moon, Venus, and Mars. *Journal of Geophysical Research* 92:E597–E601.

———. 1987*b*. Physics of magma segregation processes. In *Magmatic processes: Physiochemical principles,* ed. B. O. Mysen, pp. 69–74. Dayton, OH: Geochemical Society.

Von Tish, D., R. Allmendinger, and *J. Sharp.* 1986. History of Cenozoic extension in central Sevier Desert, west-central Utah, from COCORP seismic reflection data. Reply to discussion by Mitchell and McDonald. *American Association of Petroleum Geologists Bulletin* 70:1022–24.

Zhu, T., and *L. Brown.* 1987. Two-dimensional velocity inversion and synthetic seismogram computation. *Geophysics* 52:37–49.

■ MATERIALS SCIENCE AND ENGINEERING

Black, R., S. J. Mackwell, and *D. L. Kohlstedt.* 1986. Oxidation of fayalite (Fe_2SiO_4). Paper read at fall meeting, American Geophysical Union, 8–12 December 1986, in San Francisco, CA.

Carter, C. B. 1987. Interfaces in solid-state reactions. *Berichte der Bunsengesellschaft für Physikalische Chemie* 90:643–49.

Chen, S. H., C. B. Carter, C. J. Palmstrom, and T. Ohashi. 1987. Transmission electron microscopy studies on lateral reaction of GaAs with Ni. *Applied Physics Letters* 48:803–05.

DeCooman, B. C., and *C. B. Carter.* 1987. Faulted dipoles in GaAs. *Applied Physics Letters* 50:40–42.

Duclos, S. J., Y. K. Vohra, and *A. L. Ruoff.* 1987. hcp-to-fcc transition in silicon at 78 GPa and studies to 100 GPa. *Physical Review Letters* 58:775–77.

Fastow, R., and *J. W. Mayer.* 1987. High-energy-density pulsed ion-beam irradiation of Co/Si, Pt/Si, and Au/Si. *Journal of Applied Physics* 61:175–81.

Hui, C.-Y., K.-C. Wu, R. C. Lasky, and *E. J. Kramer.* 1987. Case-II diffusion in polymers. 1. Transient swelling. 2. Steady-state front motion. *Journal of Applied Physics* 61:5129–49.

Katcki, J. (1986.) A review of structural defect generation mechanisms in EFG ribbons. *Journal of Crystal Growth* 82:197–202.

Kohlstedt, D. L., and *S. J. Mackwell.* (1986.) High-temperature stability of San Carlos Olivine. *Contributions to Mineralogy and Petrology* 95:226–30.

Lad, R. J., and *J. M. Blakely.* 1987. Initial oxidation and sulfidation of a $Ni_{60}Fe_{40}$(100) alloy surface. *Surface Science* 179:467.

Leibovich, S. 1986. Waves and bifurcations in vortex filaments. In *Vortex dominated flows,* ed. R. Voigt and M. Husseini, pp. 3–15. New York: Springer-Verlag.

Mills, P. J., J. W. Mayer, E. J. Kramer, G. Hadziioannou, P. Lutz, C. Strazielle, P. Rempp, and A. J. Kovacs. 1987. Diffusion in polymer rings in linear polymer matrices. *Macromolecules* 20:513–18.

Nastasi, M., J.-P. Hirvonen, M. Caro, E. Rimini, and *J. W. Mayer.* 1987. TiC, Ti, and C as a mixing barrier for Ni-Si ion beam mixing. *Applied Physics Letters* 50:177–79.

Ober, C. K., and M. L. Hair. (1986.) The effect of temperature and initiator levels on the dispersion polymerization of polystyrene. *Journal of Polymer Science* 25:1395–1407.

Ober, C. K., and K. P. Lok. 1986. Formation of large monodisperse copolymer particles by dispersion polymerization. *Macromolecules* 20:268–73.

Sawyer, L. C., and *D. T. Grubb.* 1987. *Polymer microscopy.* New York: Chapman and Hall.

Schaus, C. F., J. R. Shealy, *L. F. Eastman, B. C. DeCooman,* and *C. B. Carter.* 1987. Improved GaAs/AlGaAs quantum well heterostructures by organometallic vapor phase epitaxy. *Journal of Applied Physics* 59:678–80.

Sickafus, K. E., and *S. L. Sass.* 1987. Grain boundary structural transformation induced by solute segregation. *Acta Metallurgica* 35:69–79.

Simpson, Y. K., and *C. B. Carter.* 1987*a.* Identification of α-alumina surface structures by electron diffraction. *Journal of the American Ceramic Society* 69:C217–20.

———. 1987*b.* Thin-film reactions. *Berichte der Bunsengesellschaft für Physikalische Chemie* 90: 676–80.

Sura, V. M., and *D. L. Kohlstedt.* 1987. State-variable analysis of inelastic deformation of TiC single crystals. *Journal of the American Ceramic Society* 70: 315–20.

Weir, S. T., Y. K. Vohra, and *A. L. Ruoff.* 1987. Pressure induced metallization of BaSe. *Physical Review B* 35:874–76.

■ MECHANICAL AND AEROSPACE ENGINEERING

Anand, M. S., and *S. B. Pope.* 1987. Calculations of premixed turbulent flames by PDF methods. *Combustion and Flame* 67(2):127–42.

Aubry, N., P. Holmes, J. L. Lumley, and *E. Stone.* 1987. Models for coherent structures in the wall layer. In *Advances in turbulence,* ed. G. Comte-Bellot and J. Mathieu, pp. 346–56. Berlin: Springer-Verlag.

Avedisian, C. T. 1987. An experimental study of high-pressure bubble growth within multicomponent liquid droplets levitated in a flowing stream of another immiscible liquid. *Proceedings of the Royal Society of London A* 409:271–85.

Caughey, D. A. 1987. Computational aerodynamics. In *The encyclopedia of science and technology,* ed. R. A. Meyers, vol. 3, pp. 285–304. NY: Academic Press.

Dawson, P. R., G. M. Eggert, and *K. K. Mathur.* 1987. Mechanics of metal forming. In *Proceedings, 10th U.S. National Congress of Applied Mechanics,* pp. 267–78. NY: American Society of Mechanical Engineers.

Eggert, G. M., and *P. R. Dawson.* 1987. On the use of internal variable constitutive equations in the transient forming processes. *International Journal of Mechanical Sciences* 28(9):563–89.

Gouldin, F. C. 1987. An application of fractals to modeling premixed turbulent flames. *Combustion and Flame* 68:249–66.

Gouldin, F. C., R. W. Schefer, S. C. Johnson, and W. Kollman. 1986. Nonreacting turbulent mixing flows. *Progress in Energy and Combustion Science* 12: 257–303.

Greenberg, D. P., M. F. Cohen, and *K. E. Torrance.* 1986. Radiosity: A method for computing global illumination. *The Visual Computer* 2:291–97.

Kuo, C. C., and *S. L. Phoenix.* 1987. Recursions and limit theorems for the strength and lifetime distributions of a fibrous composite. *Journal of Applied Probability* 24(1):137–59.

Leibovich, S., S. N. Brown, and *Y. Patel.* 1986. Bending waves on inviscid columnar vortices. *Journal of Fluid Mechanics* 173:595–624.

Li, X., and *D. L. Taylor.* 1987. Nonsynchronous motion of squeeze film damper systems. *Journal of Tribology* 109(1):169–76.

Lumley, J. L. 1986. Evolution of a non-self-preserving thermal mixing layer. *Physics of Fluids* 29(12):3976–81.

———. 1987. Turbulence modeling. In *Proceedings, 10th U.S. National Congress of Applied Mechanics,* ed. J. P. Lamb, pp. 33–39. New York: American Society of Mechanical Engineers.

Lyrintzis, A. S., and *A. R. George.* 1987. Transonic blade-vortex interactions: The far field. Paper read at American Helicopter Society National Specialists' Meeting on Aerodynamics and Aeroacoustics, 25–27 February 1987, in Arlington, TX.

Pope, S. B. 1987. Turbulent premixed flames. In *Annual Review of Fluid Mechanics,* ed. *J. L. Lumley,* M. Van Dyke, and H. L. Reed, pp. 237–70. Palo Alto, CA: Annual Reviews.

Pope, S. B., and *D. C. Haworth.* 1987. The mixing layer between turbulent fields of different scales. In *Turbulent shear flows,* ed. F. Durst, B. E. Launder, *J. L. Lumley,* et al., vol. 5, pp. 44–53. Berlin: Springer-Verlag.

Sarkar, S., and *J. L. Lumley.* 1987. Angular dispersion of material lines in isotropic turbulence. *Physics of Fluids* 30(5):1269–71.

Smith, W. A., and *D. A. Caughey.* 1987. Multigrid solution of inviscid transonic flow through rotating blade passages. Paper no. AIAA-86-0608 read at American Institute of Aeronautics and Astronautics 25th Aerospace Sciences Meeting, 12–15 January 1987, in Reno, NV.

Wang, V. W., *C. A. Hieber,* and *K. K. Wang.* 1986. Dynamic simulation and graphics for the injection molding of three-dimensional thin parts. *Journal of Polymer Engineering* 7:21–45.

———. 1987. C-FLOW: A CAE package with high-level interactive graphics. In *Applications of computer aided engineering in injection molding,* ed. L. T. Manzione, pp. 229–46. New York: Hanser.

Wang, W. P., and *K. K. Wang.* 1986. Geometric modeling for swept volume of moving solids. In *Proceedings, Computer Graphics and Applications,* pp. 8–17. New York: Institute of Electrical and Electronics Engineers.

Yokota, J. W., and *D. A. Caughey.* 1987. An L-U implicit multigrid algorithm for the three-dimensional Euler equations. Paper no. AIAA-87-0453 read at 25th Aerospace Sciences Meeting, American Institute of Aeronautics and Astronautics, 12–15 January 1987, in Reno, NV.

■ OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

Domich, P., R. Kannan, and *L. E. Trotter, Jr.* 1987. Hermite normal form computation using modulo determinant arithmetic. *Mathematics of Operations Research* 12:50–59.

Duffy, D. E., and *T. J. Santner*. 1987. Confidence intervals for a binomial parameter based on multistage tests. *Biometrics* 43:81–94.

Heath, D., S. Orey, V. Pestien, and W. Sudderth. 1987. Minimizing or maximizing the expected time to reach zero. *SIAM Journal of Control and Optimization* 25:195–205.

Heath, D. C., and *P. Sanchez*. 1986. On the adequacy of pseudo-random number generators. *Operations Research Letters* 5:3–6.

Prabhu, N. U. 1986*a*. Comments on two papers on queueing theory by J. Kiefer and J. Wolfowitz. *Queueing Systems* 1:311–15.

———. 1986*b*. Stochastic comparison of bulk queues. *Queueing Systems* 1:265–77.

Santner, T. J., and *D. E. Duffy*. 1986. A note on A. Albert and J. A. Anderson's conditions for the existence of maximum likelihood estimates in logistic regression models. *Biometrika* 74:755–58.

Santner, T. J., and *D. Wypij*. 1987. Fundamentals of statistics for orthopaedists. 4. *Journal of Bone and Joint Surgery* 69A:463–70.

Todd, M. J. 1986. The symmetric rank-one quasi-Newton method is a space dilation subgradient algorithm. *Operations Research Letters* 5:217-19.

Todd, M. J., and *B. P. Burrell*. 1986. An extension of Karmarkar's algorithm for linear programming using dual variables. *Algorithmica* 1:409–24.

Trotter, L. E., Jr., and D. B. West. 1987. Two easy duality theorems for product partial orders. *Discrete Applied Mathematics* 16:283–86.

■ PLASMA STUDIES

Busby, K. O., *J. B. Greenly*, *D. A. Hammer*, *Y. Nakagawa*, and *P. D. Pedrow*. 1986. Propagation of intense ion beams across a plasma-filled magnetic cusp. *Journal of Applied Physics* 60:4095–4101.

Greenly, J. B., *G. D. Rondeau*, *H. T. Sheldon, Jr.*, *D. A. Hammer*, and *P. L. Dreike*. 1986. Ion beam opening switch. In *Proceedings, 6th International Conference on High-Power Particle Beams*, ed. C. Yamanaka, pp. 890–93. Osaka, Japan: Osaka University.

Greenly, J. B., *M. Ueda*, *G. D. Rondeau*, and *D. A. Hammer*. 1986. Magnetically-insulated ion diode with a gas-breakdown plasma -anode. In *Proceedings, 6th International Conference on High-Power Particle Beams*, ed. C. Yamanaka, pp. 196–99. Osaka, Japan: Osaka University.

Hammer, D. A., *J. B. Greenly*, *P. D. Pedrow*, *E. Schamiloglu*, and *R. N. Sudan*. Intense ion ring applications to magnetic fusion. In *Proceedings, 6th International Conference on High-Power Particle Beams*, ed. C. Yamanaka, pp. 391–94. Osaka, Japan: Osaka University.

Rondeau, G. D., *C. Peugnet*, *J. B. Greenly*, *D. A. Hammer*, *B. R. Kusse*, *E. Pampellonne*, and *R. N. Sudan*. 1986. Ion diode experiments at the 0.5 TW level on the LION accelerator. In *Proceedings, 6th International Conference on High-Power Particle Beams*, ed. C. Yamanaka, pp. 180–83. Osaka, Japan: Osaka University.

■ THEORETICAL AND APPLIED MECHANICS

Brunsden, V., and *P. J. Holmes*. 1987. Power spectra of strange attractors near homoclinic orbits. *Physics Review Letters* 58(17):1699–1702.

Burns, J. A. 1987. We must pay the price for space leadership. *New York Times*, p.A16, 19 January 1987.

Burns, J. A., *M. Harwit*, et al. (1986.) *The crisis in space and earth sciences: A time for a new commitment*. Report of the National Aeronautics and Space Administration's Space and Earth Sciences Advisory Committee. Washington, DC: NASA.

Holmes, P. J. (1987.) The dynamics of coherent structures in boundary layers. Paper read at University of California Conference on Nonlinear Science, 27–28 March 1987 in Santa Barbara, CA.

Knoll, H. A., and *H. D. Conway*. 1987. Analysis of blink-induced vertical motion of contact lenses. *American Journal of Optometry and Physiological Optics* 64(2):153–5.

Moon, F. C., *J. Cusumano*, and *P. J. Holmes*. 1987. Evidence for homoclinic orbits as a precursor to chaos in a magnetic pendulum. *Physica D* 24:383–90.

Pao, Y.-H. 1987. Theory of acoustoelasticity and acoustoplasticity. In *Solid mechanics research for quantitative non-destructive evaluation*, ed. J. D. Achenback and Y. Rajapakse, pp. 257–73. Dordrecht, The Netherlands: Martinus Nijhoff.

Schaffer, L., and *J. A. Burns*. (1986.) The dynamics of weakly charged dust: Motion through Jupiter's gravitational and magnetic fields. *Journal of Geophysical Research* 92:2264–80.

Showalter, M. R., *J. A. Burns*, J. N. Cuzzi, and J. B. Pollack. (1986.) Jupiter's ring system: New results on structure and particle properties. *Icarus* 69:458–98.

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