The
BRIDGE

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THE NATIONAL ACADEMIES

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

Editorial

John H. Gibbons, former assistant to the president for science and technology and former director of the congressional Office of Technology Assessment, is a member of the NAE. He chaired the organizing committee for the October 2000 NAE symposium on Earth Systems Engineering, held as part of the Academy's 2000 Annual Meeting.

Toward Equilibrium

Years ago I was fascinated by an antique that was highly prized by my great aunt. It was a songbird in a gilded cage that when wound up would move about gracefully and sing a lovely tune. It was crafted in the latter part of the 19th century, a time when many thought of the Newtonian world as mechanically replicable to a large degree. We soon found (e.g., with nuclear discoveries) that our world is exquisitely more complex than we had ever thought. Things haven't been the same since.

When World War II ended, industrial countries capitalized on explosive advances in science and technology to create a plethora of goods and services not only for the military but also for the civilian economy. We were fast becoming as rich as Croesus. We soon found, however, that we were also sitting on a fast-rising garbage pile created by our production processes and lifestyles. John Kenneth Galbraith's *The Affluent Society* and Rachael Carson's *Silent Spring* drew attention to the fact that the *means* through which we were achieving our *ends* of material wealth were seriously threatening the environment and human health.

In response, beginning in the 1970s, Congress enacted laws to regulate pollution and protect the environment. The S&T community began to devise ways to continue to provide material "goods" with many fewer environmental "bads." Scientists and engineers undertook major research efforts to gain a better understanding of the dynamics of the biosphere.

Over the past 30 years these efforts have met with outstanding success. Our economic expansion and population growth have not seemed to cause serious environmental damage. Through innovative engineering, we have managed this progress with extremely modest net investment, to the great surprise of many naysayers.

In the process, we've learned a lot about the functions and frailties of natural ecosystems (e.g., fresh water cycles, weather and climate, stratospheric ozone, ocean currents, biological diversity). We are now also cognizant of the magnitude and complexity of the environmental challenges that remain as human economic activity continues apace. We ought not to underestimate the difficulties that lie ahead. Like economist Paul Anderson, we need to recognize that all problems, however complicated, become even more complicated when we examine them up close.

Innovative engineering will be a key tool in helping address emerging global threats caused—or exacerbated—by human activities. Climate change, loss of species, destruction of water resources, depletion of fossil fuels, and difficulties associated with creating the infrastructure to accommodate 5 billion (or more) additional people in this century are among the challenges engineers must help solve. In all cases, we are wrestling with issues of such complexity that new ways of working and communicating will be required. And, since these are global issues, they must be addressed in a globally cooperative manner. Thomas Jefferson's call for institutional flexibility is newly relevant: "As new discoveries are made, new truths discovered, and manners and opinions changed with the pace of circumstances, institutions must advance also to keep pace with the times."

The fact is that our ability to cause planetary change through technology is growing faster than our ability to understand and manage the technical, social, economic, environmental, and ethical consequences of such change.

Is the sky falling? Certainly not in the near term. But consider the problem from a longer-term perspective. While it may take several hundred years to accumulate, the damage caused by a "population/technology bolide" could have greater impact on the biosphere than the asteroid that caused the K-T boundary extinction. True, Earth recovered from the K-T collision, but it took literally millions of years to do so!

I believe that we possess the ability—or could soon attain it—to foresee and to forestall many if not most of the undesired impacts of human activities. The challenge to the engineering community is three-fold. First, working in partnership with science and other intellectual domains, it must devise a way to analyze and understand the nature and dynamics of global environmental systems. Second, it must create processes, products, and infrastructures that facilitate the "good life" in a material sense (but with minimum net material flow in the economy), while assuring a healthy, diversified environment as we all work to stabilize population. Third, it must work more directly with political leaders to construct thoughtful public policies that protect the global commons as we move, in the next century or two, toward dynamic equilibrium. It will take that long if we mean to do it gracefully. If we delay action, the journey will be much more difficult, because exponentials *are* divergent, so what is difficult now could soon be intractable if left unattended.

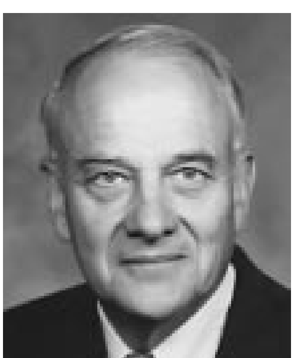
The NAE symposium on Earth Systems Engineering, held as part of the Academy's 2000 Annual Meeting, among other things served as a wake-up call to the engineering community. We have a unique and critical role to play in guiding the nonlinear and complex system of humanity-technology interaction from exponentiation to equilibrium. Papers from the symposium will appear in the Spring 2001 issue of *The Bridge*.

John H. Gibbons

Great Achievements and Grand Challenges

Wm. A. Wulf

Poised as we are between the twentieth and twenty-first centuries, it is the perfect moment to reflect on the accomplishments of engineers in the last century and ponder the challenges facing them in the next.



Wm. A. Wulf is president of the National Academy of Engineering. This article is a revised version of the talk he gave 22 October at the 2000 NAE Annual Meeting.

This past February, working with the engineering professional societies, the NAE selected the 20 greatest engineering achievements of the twentieth century. The main criterion for selection was *not* technical "gee whiz," but how much an achievement improved people's quality of life. The result is a testament to the power and promise of engineering.

Reviewing the list, it's clear that if *any* of its elements were removed our world would be a very different place—and a much less hospitable one. The list covers a broad spectrum of human endeavor, from the vast networks of the electric grid (no. 1) to the development of high-performance materials (no. 20). In between are advancements that have revolutionized virtually every aspect of the way people live (safe water, no. 4, and medical technologies, no. 16); the way people work (computers, no. 8, and telephones, no. 9); the way people play (radio and television, no. 6); and the way people travel (automobile, no. 2, and airplane, no. 3).

In announcing the achievements, former astronaut Neil Armstrong noted that, "Almost every part of our lives underwent profound changes during the past 100 years thanks to the effort of engineers, changes impossible to imagine a century ago. People living in the early 1900s would be amazed at the advancements wrought by engineers." He added, "As someone who has experienced firsthand one of engineering's most incredible advancements—space exploration—I have no doubt that the next 100 years will be even more amazing."

Given the immediacy of their impact on the public, many of the achievements seem obvious choices, such as the automobile and the airplane. The impact of other achievements are less obvious, but nonetheless introduced changes of staggering proportions.

Engineering is all around us, so people often take it for granted.

The no. 4 achievement, for example, the mechanisms to supply and distribute safe and abundant water, together with sanitary sewers, literally changed the way Americans lived and died during the last century. In the early 1900s, waterborne diseases like typhoid fever and cholera killed tens of thousands of people annually, and dysentery and diarrhea, the most common waterborne diseases, were the third largest cause of death. By the 1940s, however, water treatment and distribution systems devised by engineers had almost totally eliminated these diseases in America and other developed nations.

Engineering is all around us, so people often take it for granted. Engineering develops consumer goods, builds the networks for highway, air, and rail travel, creates innovations like the Internet, designs artificial heart valves, builds lasers for applications from CD players to surgical tools, and brings us wonders like imaging technologies and conveniences like microwave ovens and compact discs. In short, engineers make our quality of life possible.

The NAE's full list of engineering achievements, with an expanded explanation of each item, can be found on the Web at www.greatachievements.org. The short form of the list appears below:

1. Electrification—Vast networks of electricity provide power for the developed world.

2. Automobile—Revolutionary manufacturing practices made cars more reliable and affordable, and the automobile became the world's major mode of transportation.

3. Airplane—Flying made the world accessible, spurring globalization on a grand scale.

4. Water Supply and Distribution—Engineered systems prevent the spread of disease, increasing life expectancy.

5. Electronics—First with vacuum tubes and later with transistors, electronic circuits underlie nearly all modern technologies.

6. Radio and Television—These two devices dramatically changed the way the world receives information and entertainment.

7. Agricultural Mechanization—Numerous agricultural innovations led to a vastly larger, safer, and less costly food supply.

8. Computers—Computers are now at the heart of countless operations and systems that impact our lives.

9. Telephone—The telephone changed the way the world communicates personally and in business.

10. Air Conditioning and Refrigeration—Beyond providing convenience, these innovations extend the shelf-life of food and medicines, protect electronics, and play an important role in health care delivery.

11. Highways—44,000 miles of U.S. highways enable personal travel and the wide distribution of goods.

12. Spacecraft—Going to outer space vastly expanded humanity's horizons and resulted in the development of more than 60,000 new products on Earth.

13. Internet—The Internet provides a global information and communications system of unparalleled access.

14. Imaging—Numerous imaging tools and technologies have revolutionized medical diagnostics.

15. Household Appliances—These devices have eliminated many strenuous, laborious tasks, especially for women.

16. Health Technologies—From artificial implants to the mass production of antibiotics, these technologies have led to vast health improvements.

17. Petroleum and Petrochemical Technologies—These technologies provided the fuel that energized the twentieth century.

18. Laser and Fiber Optics—Their applications are wide and varied, including almost simultaneous worldwide communications, noninvasive surgery, and point-of-sale scanners.

19. Nuclear Technologies—From splitting the atom came a new source of electric power.

20. High-performance Materials—They are lighter, stronger, and more adaptable than ever before.

Challenges for the 21st Century

So much for the achievements of engineering in the twentieth century; now let's look forward to the challenges of the twenty-first.

I am an optimist. I believe 2100 will be "more different" from 2000 than 2000 was from 1900. I believe that the differences will bring further improvements in our quality of life, and that these improvements will be extended to many more of the people on the planet. But that is a belief, not a guarantee—and there are profound challenges twixt here and there.

Some of those challenges are reflected in the NAE program initiatives: megacities, Earth systems engineering, technological literacy of the general public, and so on. Rather than talk about all of these challenges, I want to talk in depth about just one. It's a challenge that I haven't written or spoken about yet, that I believe may be the greatest challenge for the twenty-first century, that I want to start an NAE program on, and that I want to begin a dialogue with you about. The challenge is *engineering ethics!*

Let me start by being clear that I believe engineers are, on the whole, very ethical. Indeed, ethics is a subject of great concern in engineering, reflecting the profession's responsibility to the public. There are ethics courses at many engineering schools. There is a bewildering array of books on the subject. Every engineering society has a code of ethics—most start with something like "… hold paramount the health and welfare of the public."[1] These codes typically go on to elaborate the engineer's responsibility to clients and employers, the engineer's responsibility to report dangerous or illegal acts, the engineer's responsibility with respect to conflicts of interest, and so on.

Beyond the codes are the daily discussions that occur in the work of engineering. I have vivid memories of discussions with my father and uncle, with my professors, and with many colleagues—about everything from design margins to dealing with management pressure to cases where tough choices had to be made.

All of that is still in place. It's part of why I am proud to be an engineer!

So, why do I want to talk about engineering ethics? Why do I believe it may be the greatest challenge of the twenty-first century? Why do I think we need to start an NAE program activity on the topic? As you know, engineering is changing, and it is changing in ways that raise new ethical issues. These new issues are, I believe, "macroethical" ones that are different in *kind* from those that the profession has dealt with in the past.

The literature on engineering ethics, the professional society codes, and the college ethics courses all focus on the behavior of *individual* engineers; these have been called "microethical" issues. The changes I will discuss pose new questions for the *profession* more than for the individual.

I want to start an NAE program on engineering ethics.

In medicine, the microethical issues are very similar to those in engineering. But, in addition, there are many macroethical issues.. For example, the individual medical doctor cannot and should not make broad policy decisions about "allocation"—who should receive scarce organs for transplant, or doses of a limited stock of medicine, or even the doctor's attention when there are more ill than can be accommodated. The profession, or better, society *guided* by the profession, needs to set these policies.

Several things have changed to create these new macroethical questions in engineering, but I am going to focus on one: complexity. Moreover, I will focus specifically on complexity arising from the use of information technology and biotechnology in an increasing number of products. The key point is that we are increasingly building engineered systems that, because of their inherent complexity, have the potential for behaviors that are impossible to predict in advance.

Let me stress what I just said. It isn't just *hard* to predict the behavior of these systems, it isn't just a matter of taking more into account or thinking more deeply—it is *impossible* to predict all of their behaviors.

There is an extensive literature on engineering failures—the Titanic, Three Mile Island, etc. Engineering has, in fact, advanced and made safer, more reliable products because it has been willing to analyze its failures. I found two books on such failures particularly interesting: *Normal Accidents,* by Charles Perrow (1985, Basic Books[2]) and *Why Things Bite Back,* by Ed Tenner (1997, Vintage Books).

It isn't just hard to predict the behavior of these systems, it's *impossible.*

I found them interesting because of the progression in thinking in the 12 years between them about why systems fail and what engineers should do about it. For Perrow, the problem is that we don't think about multiple failures happening at once in "tightly coupled systems"—and the clear implication is that the solution is to think about them! For Tenner, there is a beginning of a glimmer that very complex systems have behaviors that are *really* hard to predict. But one still gets the feeling that if we just thought about it harder, if we just thought in the larger context in which the system is embedded, we would anticipate the problems.

Perrow and Tenner are not engineers—one is a historian and the other a sociologist—and they use the tools of their disciplines to analyze why failures happen. Mathematics isn't one of those tools, and so they are unlikely to have encountered the technical explanation I am about to give you. And, of course, they are partly right about the earlier failures they analyze—those systems may not yet have crossed the threshold beyond which prediction is impossible.

Over the last several decades a mathematical theory of complex systems has been developing. It's still immature compared to the highly honed mathematical tools that are the heart of modern engineering, but one thing is very solid—*a sufficiently complex system will exhibit properties that are impossible to predict a priori!*

"Emergent Properties" and Intractability

I said the theory was "immature"—unfortunately, it also carries some undeserved baggage. The term used for these unanticipated behaviors is "emergent properties," a term that originally arose in the 1930s in "soft" sociological explanations of group behaviors. Some postmodern critics of science have also tried to use the theory to discredit reductionist approaches to scientific research. Despite this baggage, there are solid results, and impossibility (or "intractability," to use a more technical term) is one of them.

I don't want to get technical, but I need to give you a flavor of why I say impossible. Consider the question of why software is so unreliable. There are many reasons, but one of them is not "errors" in the sense that we usually use the term. In these cases the software is doing exactly what it was designed to do; it is running "to spec." The problem is that the implications of the specified behavior were not fully understood because there are so many potential circumstances, and the software designers simply couldn't anticipate them all. Not *didn't,* but *couldn't!* There are simply too many to analyze!

Let me just give you an idea of the magnitude of the numbers. The number of atoms in the universe is around 10^{100}. The number of "states" in my laptop, the configuration of 1s and 0s in its memory, is about $10^{10000000000000000000}$. That's just the number of states in the primary memory; it doesn't include those on the disk.

If every atom in the universe were a computer that could analyze 10^{100} states per second, there hasn't been enough time since the Big Bang to analyze all the states in my laptop. When I say that predicting the behavior of complex systems is impossible, I don't mean that there isn't a process that, given enough time, could consider all the implications—*it's that there isn't enough time!*

So, that's what has changed. We can, and do, build systems not all of whose behaviors we can predict. We do, however, know that there will be some such unpredicted behaviors—we just don't know what they will be.

The question then is: How do we *ethically* engineer when we know this—when we know that systems will have behaviors, some with negative or even catastrophic consequences—but we just don't know what those behaviors will be?

Note that it wouldn't be an ethical question if we didn't anticipate that systems would have these negative properties. Ethicists and the courts alike have long held that if an engineer couldn't reasonably know the consequences of his or her actions, that's okay. But here we know! So how should we behave? How should we "engineer?"

Everything Connected to Everything

A concrete example is the programmatic theme the NAE has embarked on: Earth Systems Engineering. Clearly the biosphere, our planet, is not fully understood and is a very complex, interconnected system. It's a clear example of a system where "everything is connected to everything." Every action will have an effect on the whole, albeit perhaps not a large one in most cases. (But we have many examples where we thought that an action wouldn't have a large negative impact, and it did.) It's a system where, even if we did understand all the parts, we would not be able to predict all of its behaviors.

Moreover, we must recognize that the Earth is already a humanly engineered artifact! Whether we consider *big* engineering projects, as in the proposed restoration of the Everglades, or simply paving over a mall parking lot that happens to feed an aquifer vital to a community hundreds of miles away, we have changed the planet.

Consider the case of the Everglades—either we do something or we don't; both are conscious acts. Either way, knowing that we can't predict all of the consequences, how do we proceed ethically? How do we behave? How do we choose? Clearly these are deep issues, and issues for the whole profession, not the individual engineer. The kind of ethics embodied in our professional codes doesn't tell us what to do.

This spring, Bill Joy, cofounder and chief engineer of Sun Microsystems, raised a somewhat related, but different, issue. In what I thought was an irresponsibly alarmist article in *Wired* magazine (8.04), Joy mused that the interaction of information technology, nanotechnology, and biotechnology would lead to self-replicating systems that would "replace" human beings.

He then raised the question of whether we should stop research on some or all of these technologies. I abhor the way that Joy raised the question, but I think we have to deal with the fact that something like it is at the root of the public's concerns over cloning, genetically modified organisms, etc. We are meddling with complex systems; how can the public be assured that we know all of the consequences of that meddling?

I am repelled, however, by the notion that there is truth we should not know.

I can embrace the notion that there are ways we should not *learn* truth, research methods we should not use—the Nazi experiments on humans, or perhaps even fetal tissue research, for example. I can embrace the notion that there are unethical, immoral, and illegal ways to use our knowledge. But I can't embrace the notion that there is truth, knowledge, that we should not know.

I am repelled by the notion that there is truth we should not know.

It's ironic that the first academies in the seventeenth century were created because science, this new way of knowing truth, was not accepted by the scholastic university establishment. More than 100 years later, Thomas Jefferson made a radical assertion, when, in founding the University of Virginia, the first secular university in the Americas, he said, "This institution will be based on the illimitable freedom of the human mind. For here we are not afraid to follow the truth wherever it may lead …"

That's the spirit of the pursuit of knowledge that I teethed on. Yet here I am in the Academy asking whether there is truth we should not know.

Alas, I also have to admit that the history of the *misuse* of knowledge is not encouraging.

I do not know the answer to Joy's question, but it is also a macroethical one; it is not an issue for each of us individually. You might reasonably ask why we engineers need to ponder this as *our* ethical question? It's because science is about discovering knowledge; engineering is about *using* knowledge to solve human problems. So, while I can't bring myself to agree with the implied answer in Bill Joy's question, I do believe it raises a deep question for engineers about the use of knowledge.

How should we behave to ensure proper use of knowledge? Again, it's a question for the profession, not the individual. While an individual engineer perhaps should object to improper use of knowledge, such an act by itself will not prevent misuse. We need a guideline.

I could give other examples of new macroethical issues that engineering must face, but let me just summarize.

Engineering—no, *engineers*—have made tremendous contributions to the quality of life of citizens of the developed world. There have been missteps, and there is much to be done even to bring the benefit of today's technology to the rest of the world. But I am unabashedly optimistic about the prospects for further increasing our quality of life in the twenty-first century and for spreading that quality of life around the globe.

However, that is not guaranteed. There are significant challenges, and, in fact, those challenges are not a bad operational definition of what the NAE program should be. One of these challenges, and perhaps the greatest one, is a class of macroethical questions that engineers must face. There are many such issues, but I chose two to illustrate the point.

Projects such as the further modification of the Everglades will be done with imperfect knowledge of all of the consequences. They *should* be done with the certainty that some of the consequences will be negative—perhaps even disastrous. At the same time we do not have the luxury of "opting out." Not to act is also an action, so we must address the question of what constitutes ethical behavior under such circumstances. Does the current nature of the engineering process support, or even allow, such behavior?

A separate but related question is how we ethically use the increasing knowledge we have of the natural world and the power that knowledge gives us to modify nature, which I think is the substantive question raised by Bill Joy's article.

Both of these are questions on which society must give us guidance—our professional codes do not address them. But we must raise the issue and provide society with the information to help it decide, and we had better do it soon!

I happened on a quote from John Ladd, emeritus professor of philosophy at Brown, that captures part of the point I have tried to raise. He said, "Perhaps the most mischievous side effect of [ethical] codes is that they tend to divert attention from the macroethical problems of a profession to its microethical ones." Our ethical codes are very important, but now we have another set of issues to address. Let's not let our pride in one divert us from thinking hard about the other.

Notes

1. This particular wording is from the National Society of Professional Engineers code, but many others are derived from it and use similar language.

2. Charles Perrow released an updated edition of *Normal Accidents* in 1999 (Princeton University Press).

A 21st Century Renaissance

George M. C. Fisher

Technology, humanism, and cross-disciplinary cooperation can combine to take us farther than we dreamed we could go.

George M. C. Fisher is chairman of the board of Eastman Kodak Company and chair of the NAE. He delivered these remarks 22 October at the 2000 NAE Annual Meeting.

Good afternoon, and congratulations to our new members. I know you will find your experience with the NAE rewarding.

Few organizations have so great an effect on the future. And our influence is bound to grow. I come to that conclusion by analyzing the Academy as if it were a business. Consider our customer base, which is the government and the public interest. What more influential constituencies could be served!? Consider our product, which is *knowledge*. It's growing in value as technology becomes more complex and plays a larger role in public policy.

Beyond the strength of that business case, we have the good fortune to serve the NAE during an extraordinary period in history. As a nation, the United States has achieved a level of prosperity and technological leadership unequalled in human experience. No country has ever been so rich in resources. No country has ever been better positioned to improve the human condition through its technologies.

Of course there are obstacles. But there is one threat to progress we can eliminate, and that is *low expectations!*

Given our current situation, we have good reason to set our sights high. We should expect advancements greater than those of the Italian Renaissance. I think it's both rational and helpful to envision a "21st Century Renaissance"—and picture the coming years as a period of unprecedented achievement.

The technology engine that drove the first Renaissance was the printing press. Today, it's digital computing and communication that allow faster, wider access to the best information, tools, and practices. Information technology is enabling faster development of more fundamental breakthroughs in virtually every field, including materials, energy, and biotechnology.

If you measure progress in engineering by degrees of precision, we have come far. Engineers are now controlling photons of light with optoelectronics and working at the atomic level with nanotechnology. Few people would question our capacity for great technological achievements—certainly few in this audience.

Assessing technology from a humanist perspective will be the greatest challenge we face.

The scale of accomplishments on the horizon makes the Renaissance idea rational. I believe that what makes it appealing is humanism, the force at the heart of the first Renaissance. It placed human needs and aspirations at the center of every endeavor.

Assessing technology from a humanist perspective will, I think, be the greatest challenge we face at the NAE in the coming years. Technical knowledge is table stakes. We must also be aware of public priorities, environmental and health concerns, and difficult ethical issues such as privacy. We tend to think of these as "soft" issues. They defy the kind of certainty and mastery we bring to our technical disciplines. But these soft issues are the hardest to resolve.

Ultimate responsibility lies with policymakers. But we can help by considering these issues when we assess the impact of technology, including those elusive "unintended consequences." If we are to analyze costs and benefits, we need to understand what the public perceives as important and valuable.

Integrating human needs is engineering's biggest challenge and opportunity. The Internet exemplifies what can happen when we address, intentionally or inadvertently, those needs. It gives everyone what they wanted long ago: *computers that talk to each other.* What everyone initially received instead was cheap computing power. But people needed to communicate easily and inexpensively to use their computers productively.

Simplifying Complex Devices

I believe that one of the greatest opportunities in product engineering will be in simplifying complex devices. Computers and cameras and every digital device must and will become much easier for ordinary human beings to use. The end of the twentieth century will seem like the Dark Ages in terms of convenience. And engineering a new generation of digital products that are far more convenient will drive another cycle of economic growth.

As always, it is engineers who will develop these breakthroughs. In a sense, engineering is a humanist discipline by definition. Applying technology to human needs is what we are trained to do. Even many of the standards and measures we use in our work derive from the human form, beginning with the Egyptian cubit—from elbow to fingertips—and continuing through digits, palms, hands, feet, and yards.

It's interesting to trace engineering standards to their roots. Some of those standards are surprisingly arbitrary. There's a tale told at Kodak about the origin of the 35-mm film format, which was first used for motion pictures. It's said that George Eastman asked Thomas Edison how wide the film should be for Edison's new movie camera and viewer. Edison separated his thumb and forefinger and said: "About this wide."

Now, "about this wide" is hardly consistent with today's nanolevels of precision for international standards. It may be inconsistent with the truth, too. It's more likely that a roll of 70-mm film, which was common in the 1890s, was slit in half to make 35-mm film. If this is the true source of the standard, it's just as arbitrary as the legend.

There's a similar story about the size of SRBs—solid rocket boosters—used to launch the first space shuttle. The SRBs had to be shipped by rail to the launch site.

This influenced their design. Size was limited by the load capacity of railroad cars and the width of tunnels—all of which relate to the standard distance between rails, which is exactly 4 feet, 8–1/2 inches. That standard can be traced back to the first English tramways. They were built with the same jigs and tools used to build wagons. Spacing between wagon wheels had been standardized to accommodate ruts in long distance roads. Those ruts had been worn by wagons dating back to Imperial Rome, when chariots accompanied the legions that conquered Europe and Britain. Roman chariots were engineered with a very particular wheel spacing: just wide enough to accommodate the rear ends of two horses. So the next time you see a shuttle launch, remember that one of the major design features of one of the world's most advanced transportation systems was determined by the width of a horse's rear. And the next time you see a questionable design spec, it may be appropriate to ask: "What horse's rear end was responsible for this?"

Joking aside, this is another reason the Renaissance metaphor is helpful, because it leads us to reconsider our most basic standards, assumptions, and priorities.

Engineering and Public Expectations

A Renaissance is a time of rethinking and optimism. Successful engineering has redefined the public's expectations of what we can accomplish. If we can put a man on the moon, why can't we significantly improve the environment and education? Why can't we eliminate hunger, poverty, and disease?

In answering those questions, very few Americans would say we are limited by technology. For good reason, the general public has a positive view of technology. But they also see risks—to the environment, health, safety—and have other legitimate concerns. One of our roles at the NAE is to anticipate, to see those risks first, and to help policymakers deal with them effectively. It's an important contribution, because it helps sustain this country's confidence in change driven by technology.

America's optimism and ability to change will put us at the center of the 21st Century Renaissance. As will the strides made by American industry in being the first to bring new technologies to market. This confident, aggressive approach gives us a competitive advantage as a nation.

We are very good at competing in this country. Cooperation, on the other hand, is not so natural. Certainly not between government and industry. Not between regulators and the regulated. That must change to enable a Renaissance. Those of us in the business world need to relearn a lesson from the past: some government regulation is essential to capitalism.

Half a millennium ago, capitalism grew from the bedrock of uniform legal and monetary systems. Today, the lack of a supportive legal system is a major source of Russia's difficulties. And Europeans are struggling to establish a uniform monetary system. Business leaders need to recognize and respect government's contribution to our success.

If competitors can cooperate creatively, so can business and government.

Many companies are benefiting from alliances and joint ventures with competitors. If competitors can cooperate creatively, so can business and government. We need to improve in this aspect, because the major projects that change life in the future will involve government, corporations, and universities.

Government will often drive these projects, and it will rely on the NAE for guidance. The stakes in public policy decisions will be higher than ever before. All our wealth of resources and potential for historic achievements will make the risks bigger.

This Academy was created to help policymakers avoid major pitfalls and stay on the path to progress. The NAE is a model of the Renaissance ideal, a forum for cooperation and sharing of knowledge from diverse institutions and specialties. To our work, we bring high standards of excellence and objective analysis. I'd like to propose that we also bring high expectations for the future.

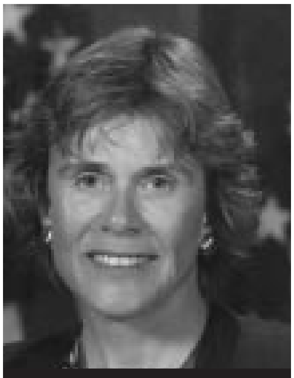
Let's think of our years here as the beginning of a 21st Century Renaissance—a time when technology, humanism, and cross-disciplinary cooperation combine to take us farther than we dreamed we could go.

This is the picture we should keep in our minds. It's a vision that can help lead us to the great achievements we have every reason to expect in the years ahead.

Digits of Pi: Barriers and Enablers for Women in Engineering

Sheila E. Widnall

Engineering must welcome women or risk becoming marginalized as other fields seek out and make a place for them.



Sheila Widnall is Institute Professor at MIT and vice president of the NAE. This article is based on a speech she presented at the NAE Southeast Regional Meeting held at Georgia Institute of Technology, 26 April 2000.

In a recent seminar with faculty colleagues, we were discussing the information content of a string of numbers. The assertion was made that the quantity of information equaled the number of bits in the string, unless you were told that, for example, the string was the digits of Pi. Then the information quantity became essentially one. The additional assertion was made that of course all MIT freshmen knew Pi out to some outrageously large number of digits. I remarked that this seemed to me like a "guy" sort of thing, and I doubted that the women at MIT knew Pi out to some large number of digits.

This got me thinking whether there are other "guy" sort of things which are totally irrelevant to the contributions that engineers make to our society but that nevertheless operate to keep women out of engineering. These "guy" things may also be real barriers in the minds of some male faculty members who may unconsciously, or even consciously, tell women that women don't belong in engineering. I have recently visited university campuses where that is still going on.

Let me make a strong statement: If women don't belong in engineering, then engineering as a profession is irrelevant to the needs of our society. If engineering doesn't make welcome space for them and embrace them for their wonderful qualities, then engineering will become marginalized as other fields expand their turf to seek out and make a place for women.

So let me give you Sheila Widnall's top 10 reasons why women are important to the profession of engineering:

10. Women are a major force in our society. They are self-conscious about their role and determined to be heard.

9. Women are 50 percent of the consumers of products in our society and make over 50 percent of the purchasing decisions.

8. To both men and women today, a profession that does not have a significant percentage of women is not an attractive career choice.

7. Women are integrators. They are experts at parallel processing, at handling many things at once.

6. Women are comfortable in fuzzy situations.

5. Women are team builders. They inherently practice what is now understood as an effective management style.

4. Engineering should be and could be the twenty-first century foundation for all of the professions.

3. Women are a major force in the professions of law, medicine, media, politics, and business.

2. Women are active in technology. Often they have simply bypassed engineering on their way to successful careers in technology.

1. Women are committed to the important values of our times, such as protecting the environment, product safety, and education, and have the political skill to be effective in resolving these issues. They will do this with or without engineering. They are going to be a huge force in the solution of human problems.

Trends in our society indicate that we are moving to a service economy. We are moving from the production of hardware to the provisions of total customer solutions. That is, we are merging technology and information and increasing the value of both. What role will the engineering profession play in this? One future vision for engineering is to create the linkage of hardware, information, and management. It seems to me that women are an essential part of this new imperative for the engineering profession, if the profession is to be central to the solution of human problems. Another possible future for engineering is to be restricted to the design of hardware. If we do this, we will be less central to the emerging economy and the needs of our society.

Women are essential to a new imperative for engineering.

The top 10 reasons why women don't go into engineering:

10. The image of that guy in high school who all of the teachers encouraged to study engineering.

9. Poorly taught freshman physics.

8. Concerns that a female with the highest math score won't get a date to the prom.

7. Lack of encouragement from parents and high school teachers.

6. Guys who worked on cars and computers, or faculty members who think they did.

5. Lack of encouragement from faculty and a survival-of-the-fittest mentality (e.g., "I treat everyone badly" attitude or constant use of masculine pronouns describing engineers).

4. Lack of women faculty or obvious mistreatment of women faculty by colleagues and departments.

3. Bias in the math SATs.

2. Lack of visible role models and other women students in engineering.

1. Lack of connection between engineering and the problems of our society. Lack of understanding what engineers do.

These issues of language, expectations, behavior, and self-esteem are still with us. Until we face them squarely, I doubt that women students will feel comfortable in engineering classrooms. No, I'm not talking about off-color stories, although I'm sure that goes on. I'm talking about jokes and innuendo that convey a message to women that they're not wanted, that they're even invisible. It may be unconscious, and it may come from the least secure of their male classmates or teachers—people whose own self-esteem is so low and who lack such self-confidence that they grasp for comments that put them at least in the top 50 percent by putting all of the women in second place. Also, many men express discomfort at having women "invade" their "space"; they literally don't know how to behave. When I was a freshman advisor I told my women students that the greatest challenge to their presence at MIT would come from their classmates who want to see themselves in at least the upper 50 percent of the class.

The authority of women faculty can be challenged in ways that would never happen to a man.

These attitudes are so fundamental that, unless they are questioned, people just go about the business of treating women as if they're invisible. I remember one incredible incident that happened to me when I was a young assistant professor. I was teaching the graduate course in aerodynamics with a senior colleague, and I was to give the first lecture. So I walked into class and proceeded to organize the course, outline the syllabus, and give the first introductory lecture. Two new graduate students from Princeton were in the class. One of them knew who I was. The other thought I was the senior professor's secretary and was very impressed at my ability to give the first lecture. I think you can all see the intellectual disconnect in this example. It never occurred to this student that I might be a professor, although I'm sure I put my name and phone number on the blackboard. So he thought there were two professors and one secretary. I did in fact eventually become a Secretary—but that is another story.

I once got a call from a female faculty colleague at another university. She was having trouble teaching her class in statistics. All of the football players who were taking it were sitting in the back row and generally misbehaving. If she asked me for advice on that today I don't know what I'd say. But what I did say—that worked—was that she should call them in one by one and get to know them as individuals. This evidently worked and she sailed on. Today she is an outstanding success. I doubt if many male faculty members have had such an experience. But this clearly was a challenge to her or she wouldn't have called me. I believe that all women faculty members have such challenges to their authority in ways that would never happen to a man. Students will call a female professor "Mrs." and a male professor "Professor." I told one student that if he ever addressed Sen. Feinstein as Mrs. Feinstein, he would find himself in the hall. If it is happening to women faculty members, I'm sure it is happening to women students, this constant challenge to who they are.

Attitudes That Impact Effectiveness

We all have unconscious attitudes that impact our effectiveness as educators and cause us to negatively impact our women students. I remember one incident when I was advising two students on an independent project—a guy and a gal (the gal was the better student). We were meeting to discuss what needed to be done and I found myself directing my comments to the guy whenever there was discussion about building, welding, or cutting. I caught myself short and consciously began to direct my comments evenly. I went to my departmental colleagues and said: "This is what happened to me. If I'm doing it, you surely are." Do male faculty members welcome the appearance of female students in the classroom? Do some resent having to teach women and feel that their departments are diminished somehow when women are a significant fraction of their students? You might think so when you notice the low percentages of women among the engineering graduate students, when the selection of candidates is more clearly controlled by such biased male faculty members.

And then there is the issue of evaluation and standards. I don't think that we as a profession can just sit by and evaluate women to see if they measure up to our current criteria. We have to reexamine the criteria. As an example, one of my faculty colleagues, whose daughter was applying to MIT—thank God for daughters—did a study of whether admissions performance measures, and primarily the math SAT, actually predicted the academic performance of students, not just as freshmen but throughout their undergraduate careers. He did this differentially for men and women and got some surprising and very important results. He found that women outperform their predictions. That is, women perform better as students than their math SAT scores would predict. The effective predictive gap is about 30 points.

Thus the conditions were set to change admissions criteria for women in a major way. The criteria for the math SAT for women were changed to reflect the results of the study. In one year, the proportion of women students in the entering class went from 26 to 38 percent.

And it worked! We have been doing this for close to 20 years now and the women have performed as we expected. Women are now about 50 percent of the freshman class.

"Critical-Mass" Effects

Along the way, we have identified some very important "critical-mass" effects for women. Once the percentage of women students in a department rises above about 15, the academic performance of the women improves. This suggests a link between acceptance and self-esteem and performance. These items are under our control. I am convinced that 50 percent of performance comes from motivation. An environment that truly welcomes women will see women excel as students and as professional engineers.

At this point, all of MIT's departments have reached this critical mass. Women now comprise 41 percent of the MIT undergraduate population and outnumber men in 3 of the 5 schools and 15 of the 22 undergraduate majors. The women are still outperforming the men.

At MIT, women are the majority in four of the eight engineering courses: chemical engineering, materials science and engineering, civil and environmental engineering, and nuclear engineering. With the possible exception of Smith College, which is starting an engineering program, I have not heard of another engineering department anywhere in which women are a majority of the undergraduate students. Women are 34 percent of the undergraduates in the entire MIT School of Engineering.

Anyone who has taught in this environment would report that it has improved the educational climate for everyone. We in aeronautics see it in our ability to teach complex system courses dealing with problems that have no firm boundaries.

The top 10 reasons why women are not welcome in engineering:

10. We had a woman student/faculty member/engineer once and it didn't work out.

9. Women will get married and leave.

8. If we hire a woman, the government will take over and restrict our options.

7. If you criticize a woman, she will cry.

6. Women can't take a joke.

5. Women can't go to offsite locations.

4. If we admit more women, they will suffer discrimination in the workplace and will not be able to contribute financially as alumni. (I kid you not; that is an actual quote.)

3. There are no women interested in engineering.

2. Women make me feel uncomfortable.

1. I want to mentor, support, advise, and evaluate people who look like me.

Women undergraduates outnumber men in 3 of MIT's 5 schools and 15 of the school's 22 majors.

So how do we increase the number of women students and make our profession a leader in tackling tough societal problems? What do we need?

Let me give you my list of the top 10 effectors:

10. Effective TV and print material for high school and junior high girls about career choices.

9. Engineering courses designed to evoke and reward different learning styles.

8. Faculty members who realize that having women in a class improves the education for everyone.

7. Mentors who seek out women for encouragement.

6. Role models—examples of successful women in a variety of fields who are treated with dignity and respect.

5. Appreciation and rewards for diverse problem-solving skills.

4. Visibility for the accomplishments of engineering that are seen as central to important problems facing our society.

3. Internships and other industrial opportunities.

2. Reexamination of admissions and evaluation criteria.

1. Effective and committed leadership from faculty and senior administration.

Technology is becoming increasingly important to our society. There may be an opportunity to engage media opinion makers in communicating opportunities and societal needs to young girls. I don't believe that the engineering profession alone can effectively communicate these messages, but in partnership we can be effective. These issues are important for our society as a whole, not just for engineering as a profession.

However, we do have a good bit of housecleaning to do. We must recognize that women are differentially affected by a hostile climate. Treat a male student badly and he will think you're a jerk. Treat a female student badly and she will think you have finally discovered that she doesn't belong in engineering. It's not easy being a pioneer. It's not easy having to prove every day that you belong. It's not easy being invisible or having your ideas credited to someone else.

What I want to see are engineering classrooms full of bright, young, enthusiastic students, male and female in roughly equal proportions, who are excited about the challenge of applying scientific and engineering principles to the technical problems facing our society. These women want it all. They want full lives. They want important work. They want satisfying careers. And in demanding this, they will make it better for their male colleagues as well. They will connect with the important issues facing our society. Then I will know that the engineering profession has a future contribution to make to our society.

NAE News and Notes

NAE Newsmakers

Zhores I. Alferov, vice president of the Russian Academy of Sciences and director of the A. F. Ioffe Physico-Technical Institute, **Herbert Kroemer,** professor of electrical engineering and of materials at the University of California, Santa Barbara, and **Jack S. Kilby,** independent consultant, Houston, Texas, received the 2000 **Nobel Prize in Physics** on 10 December. They were awarded the prize for laying "the foundations of modern information technology, particularly through their invention of rapid transistors, laser diodes, and integrated circuits."

Charles A. Amann, retired research fellow, General Motors Research Laboratories, received the **Internal Combustion Engine Award** from the American Society of Mechanical Engineers (ASME) in September. Mr. Amann was recognized "for advancing knowledge regarding the mechanical design of the automobile power plant."

John E. Breen, Nasser I. Al-Rashid Chair in Civil Engineering, the University of Texas at Austin, is the year 2000 **Laureate of the International Award of Merit** from the International Association for Bridge and Structural Engineering. The award was presented in Lucerne, Switzerland, on 18 September "in recognition of his outstanding achievements in teaching and research in structural engineering and his eminent contributions to international professional cooperation."

Aaron Cohen, Zachry Professor of Engineering, Texas A&M University, College Station, was given **Honorary Membership** by ASME International in November in recognition of his outstanding contributions to NASA's manned space flight program and his subsequent role in engineering education.

Douglas C. Engelbart, director, Bootstrap Institute, **Dean Kamen,** president, DEKA Research and Development Corporation, **Donald B. Keck,** division vice president and technology director, optical physics, Corning Inc., and **Robert D. Maurer,** retired research fellow, Corning Inc., were among the recipients of the 2000 **National Medal of Technology.** The medal is the highest honor bestowed by the President of the United States to America's leading innovators. It recognizes technological innovators who have made lasting contributions to enhancing America's competitiveness and standard of living.

Yuan-Cheng B. Fung, professor emeritus of bioengineering and applied mechanics, University of California at San Diego, is the recipient of the 2000 **National Medal of Science** in engineering. The medal was established in 1959 as a presidential award to be given to individuals "deserving of special recognition by reason of their outstanding contributions to knowledge in the physical, biological, mathematical, or engineering sciences."

Ignacio Grossman, Rudolph R. and Florence Dean Professor of Chemical Engineering, Carnegie Mellon University, was awarded the **Lifetime Achievement Award** at the Hispanic Engineers National Achievement Awards Conference (HENAAC) on 14 October in El Paso. NAE vice president **Sheila E. Widnall** made the presentation.

John C. Houbolt, retired chief aeronautical scientist, NASA Langley Research Center, received the **Spirit of St. Louis Medal** from ASME International in November. Dr. Houbolt was honored for his seminal contributions to aeroelasticity and for the lunar orbit rendezvous concept.

Gerald Nadler, IBM Chair Emeritus in Engineering Management and professor emeritus, industrial and systems engineering, University of Southern California, received a **Distinguished Service Award** from the University of Wisconsin, Madison, College of Engineering. Dr. Nadler was recognized for his many contributions to engineering. The award was presented on 20 October during the banquet for Engineers' Day at the university.

Ralph B. Peck, professor of foundation engineering, emeritus, and **Chester P. Siess,** professor emeritus of civil engineering, of the University of Illinois, Urbana-Champaign, were the featured speakers at the **Founda-**

tion Fall Lecture of the Structural Engineers Association of Illinois on 19 September. They shared reminiscences of their careers and insights regarding the future of structural engineering. NAE member **Mete Sozen,** Purdue University, moderated.

Franz F. Pischinger, president and CEO, FEV Motorentechnik, was honored with the **Soichiro Honda Medal** in November. ASME International conferred the honor on Dr. Pischinger for his significant contributions as a researcher, author, inventor, and educator, and for his founding role in FEV Motorentechnik.

Josef Singer, professor emeritus of aerospace engineering, Technion Israel Institute of Technology, was awarded the **Israel Prize 2000 in Engineering Research** for his work in the field of buckling and static and dynamic stability of thin-walled structures, including the development of innovative test methods in this field, as well as for his engineering contribution to aerospace structures.

Richard Tapia, Noah Harding Professor of Computational and Applied Mathematics, Rice University, received the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) 2000 **Distinguished Scientist Award.**

Chang-Lin Tien, University Professor and NEC Distinguished Professor of Engineering, University of California, Berkeley, was honored by Tau Beta Pi in October with the 2000 **Distinguished Alumnus Award.**

Takeo Yokobori, professor and dean, School of Science and Engineering, Teikyo University, Japan, was named a **Person of Cultural Merits,** a high national honor, on 3 November. Prof. Yokobori was selected for his work on systematizing the disciplines of strength and fracture, such as yielding, brittle fracture, fatigue, creep and fracture.

2000 Annual Meeting Report

Alfred R. Berkeley III, keynote speaker.

More than 700 members, foreign associates, and guests participated in this year's NAE Annual Meeting, which began on Saturday, 21 October, with the orientation of the Class of 2000. That evening, the NAE Council, at a formal dinner in the National Academies' Great Hall, honored the 86 newly inducted members and foreign associates, along with their guests.

The public session on 22 October began with remarks by NAE Chair **George M. C. Fisher,** chairman, Eastman Kodak Company. Dr. Fisher encouraged the membership to embrace technological advancement and to think of the NAE as a model for a "21st Century Renaissance," a period of unprecedented achievement. (See p. 11 for the full text of his remarks.)

Following Dr. Fisher, **Wm. A. Wulf,** NAE president, spoke about engineering ethics, discussing how engineering is changing in ways that raise macroethical issues, or questions for the profession more than the individual engineer. Dr. Wulf also highlighted the NAE's Greatest Engineering Achievements of the 20th Century project and how it related to the engineering of society. (See p. 5 for his remarks.)

The induction of the Class of 2000, composed of 78 members and 8 foreign associates, followed Dr. Wulf's address. Next on the program, **Charles H. Townes,** professor of the graduate school at the University of California at Berkeley, received the Founders Award "for invention of the path-breaking maser-laser principle, which is the foundation for modern electronics and communication technology, and for exceptional service to universities, government, industry, and professional societies." (See p. 24 for full text of his remarks.)

Charles M. Vest, president of the Massachusetts Institute of Technology, received the Arthur M. Bueche Award "in recognition of outstanding university leadership, commitment and effectiveness in helping mold government policy in support of research, and forging linkages between academia and industry." (His remarks begin on p. 22.)

Dr. Wulf reminded the audience that the official announcement of the recipients of the Charles Stark Draper Prize and the Fritz J. and Dolores H. Russ Prize will not be made until February 2001.

After the awards program, guest speaker Alfred R. Berkeley III, president of the NASDAQ stock market, discussed the happenings in the world of markets and the implications of those markets for science and engineering. A reception in honor of Dr. Townes and Dr. Vest was held afterward in the Great Hall.

On Monday, 23 October, a number of briefings for members were held on topics such as the next generation of vehicles, network-centric naval forces, great engineering achievements, science and technology leadership in American government, sustainable water supplies in the Middle East, and estate planning.

The spouse/guest program consisted of three tour options designed to highlight Washington, D.C.'s, artisan culture. Spouses and guests chose from trips to the Corcoran Gallery of Art, Hillwood Museum and Gardens, the John F. Kennedy Center for the Performing Arts, or the U.S. National Arboretum.

While spouses and guests enjoyed private tours, members and foreign associates participated in the NAE section meetings. The section meetings provide attendees with an opportunity to cover topics that are of critical importance to their respective disciplines and membership classifications.

This year's sections chairs are: Aerospace Engineering, **Steven D. Dorfman**, Hughes Electronics Corporation (retired); Bioengineering, **Van C. Mow**, Columbia University; Chemical Engineering, **John H. Seinfeld**, California Institute of Technology; Civil Engineering, **Loring A. Wylie, Jr.**, Degenkolb Engineers; Computer Science and Engineering, **Robert E. Kahn**, National Research Initiatives; Electric Power/Energy Systems, **John F. Ahearne**, The Scientific Research Society; Electronics Engineering, **Frederick H. Dill**, IBM Thomas J. Watson Center; Industrial, Manufacturing, and Operational Systems, **John G. Bollinger**, University of Wisconsin, Madison; Materials Engineering, **James C. Williams**, The Ohio State University; Mechanical Engineering, **Richard J. Goldstein**, University of Minnesota; Petroleum, Mining, and Geological Engineering, **Robert R. Beebe**, Homestake Mining Company; and Special Fields and Interdisciplinary Engineering, **Essex E. Finney, Jr.**, U.S. Department of Agriculture.

One of the highlights of the Annual Meeting is the ever-popular reception and dinner dance, held this year on Monday evening at the International Trade Center, with entertainment provided by Doc Scantlin.

On Tuesday, 24 October, the NAE presented a technical symposium on the theme of earth systems engineering (ESE). ESE is an emerging area of multidisciplinary study with roots in industrial ecology, environmental science, and other engineering disciplines. ESE takes a holistic view of natural and human-

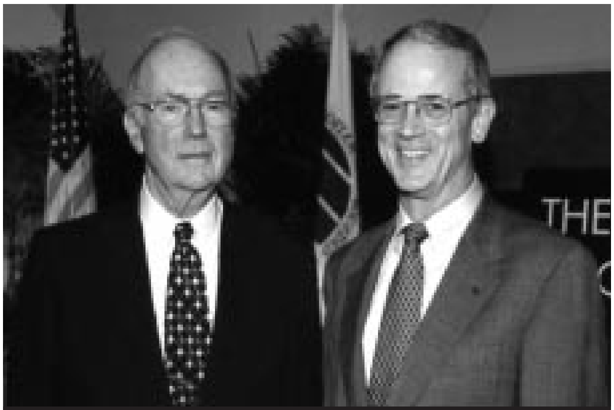
NAE Class of 2000.

system interactions, and aims to facilitate technically sound and ethically wise decisions about issues with implications on regional to global scales. **John H. Gibbons**, former assistant to the president for science and technology, hosted the symposium along with the other members of the organizing committee: Braden R. Allenby, **Robert A. Frosch**, **Lawrence T. Papay**, and Robert H. Socolow.

The symposium consisted of four sessions: "Climate Change: Engineering to Understand, Adapt, and Mitigate," with main speaker **Robert M. White**, NAE president emeritus; "Utilizing Biological Activity for Humanity's Benefit," with speaker Maxine F. Singer, Carnegie Institution of Washington; "Engineering and Policy: Partners in Developing and Implementing Solutions," with speaker **Anita K. Jones**, University of Virginia; and "Rethinking Today's Cities—Designing Tomorrow's Urban Centers," with speaker **George Bugliarello**, Polytechnic University.

The NAE will publish the proceedings for the technical symposium early in 2001. The next Annual Meeting is scheduled for 7–9 October 2001. Hope to see you there!

Bueche Awardee Remarks



Founders Awardee Charles H. Townes, professor of physics, University of California, Berkeley, and Bueche Award recipient Charles M. Vest, president of MIT. Dr. Vest made the following remarks on 22 October 2000. Dr. Townes' remarks follow.

I am deeply honored and grateful to receive the Arthur M. Bueche Award from America's National Academy of Engineering. Frankly, I find myself amazed to be included in the company of those outstanding individuals who have previously received this recognition.

In 1990 I had the privilege to become MIT's president. It seemed to me that this singular opportunity was a call to national service. It further seemed to me that this position afforded me a "bully pulpit" that could be used to call attention to the urgent need to revitalize the relationship between the federal government and our nation's public and private research universities.

The understanding of this partnership, which had been so important to the nation's spirit, prosperity, health, quality of life, and security, seemed to be slipping unnoticed into the mists of time—slipping away because of a rapid loss of "corporate memory" in the Congress, in the executive branch, and even in the university community; slipping away because of a shift in the formulation of science policy away from the executive branch and into the chaotic world of congressional appropriations; slipping away because of the end of the Cold War, with an attendant diminution of concern about science and technology as bulwarks of our national defense; slipping away because of hubris and a lack of understanding by many in our academic community of the need to talk to Congress and the public; slipping away because of lack of active interest on the part of too many leaders of industry.

Particularly unfortunate was the dissipation of bipartisan support in Congress. The decline in the sense of partnership and national purpose was exacerbated by sharpened ideological divisions, growing skepticism about universities, and the intensified competition for declining resources. And the dominant messages from our community were all too often only about the desires of individual disciplines and individual institutions.

With the tutelage and participation of Jack Crowley at MIT, and leaders of industry such as Norm Augustine and John Young, and with an ever-widening circle of my academic colleagues, I have tried to help spread the word that science and engineering are essential to our future; that it is a proper and essential role of the federal government to support research in our universities; and that the glory of this system is the intimate interweaving of research and education.

We have tried to do this within a context of respect for the political process and recognition of the real choices our legislators must make, but we have pushed for an understanding that these matters must be moved higher on the list of national priorities. While I might have secretly aspired to be a statesman of science and engineering, the truth is, I have been more of a minor operative in great company.

But something else happened during this decade. The role of the private sector changed so dramatically that we can never again think of science policy as a simple matter of government and academia. We now must think of science *and* engineering policy—or perhaps even innovation policy—and it must include private industry as well as government and academia.

Even so, the role of private industry itself is dynamic, unpredictable, and metastable. Put simplistically, U.S. corporations have changed their R&D functions dramatically. They are mostly out of the business of moderate- or long-range corporate R&D. They have gained astounding efficiencies and value by integrating near-term R&D into the broader context of product development. They now gain much of their actual innovation by buying successful start-up companies, whose intellectual capital often flows from our universities.

Will this system be stable in the long run? I don't know, but all three parties—government, industry, and academia—need to better understand and shape this system. I am not a pessimist about this; I believe it offers great opportunity for productive change.

I also believe that the role of the federal government in supporting research and advanced education will remain absolutely essential. During this past decade I have deeply appreciated the willingness of many elected and appointed leaders to listen carefully and take the long view of the national good. There are those prepared, and even enthused, to work on behalf of strong American R&D and advanced education—*if* we are willing to invest the time to work with them.

But in the final analysis, our responsibility for human capital—for educating and developing the talents of young people—is the most important agenda item of all.

The number of young American men and women pursuing science, mathematics, and engineering is declining at the very moment when science and technology are so clearly key to our future. We must turn this around.

We must make clear to young people the value of the engineering and scientific professions to our economy and quality of life. But even more, we must help students at every level experience the joy of discovery, the love of analyzing and understanding our wondrous universe, the thrill of design, and the power of synthesis and creativity.

Let me leave you with a reminder about why science and engineering are so important. The life expectancy of Americans has increased from 55 years in 1900 to nearly 80 years today—largely because of advances in science and engineering. Over 50 percent of the growth of the U.S. economy in the last 50 years is due to scientific and technological innovation, which largely flowed from our university laboratories. And science and engineering have been the ladders on which so many young people of modest financial backgrounds have climbed to the heights of American society.

The national pursuit of excellence in engineering and science is a great cause—a cause in which we, as members of the National Academy of Engineering, are joined.

Thank you again for this honor, and for giving me a bit of airtime in the process.

Founders Awardee Remarks

I am very much honored to be chosen for the Founders Award of the National Academy of Engineering, and want to express my appreciation. I have also been around long enough to have known and admired a large number of those who have received this award in previous years. This gives me a feeling of grateful humility that I can join the ranks of these impressive individuals.

My own work has very often been on what might be called the border between science and engineering. However, I don't believe any borders between the two can actually be found. The two cannot really be separated.

As a young physicist, my first job was at Bell Labs. World War II was approaching, and about a year after I began work there, the Bell Labs managers, recognizing the demands of oncoming war, directed me to begin engineering radar navigation and bombing systems. I learned a lot from that experience. It helped me recognize the potentiality for new molecular and atomic science which grew out of this field, and it has strongly affected almost all of my subsequent work.

A standard view is that science discovers new principles of how things in the universe work and that engineering applies these principles to some use for humans. But in my view, interactions between the two are much more complex and complementary. They go in both directions. It's true that engineering is much dependent on scientific discoveries and principles. But science is also much dependent on engineering developments. If one is to thrive and grow then so must the other.

For one thing, good engineering produces much of the instrumentation used in today's complex scientific experiments. But it also produces breakthroughs which generate new types of science. Semiconductor technology and solid state physics is one obvious case of this close interaction between science and engineering. Astronomy by contrast might seem to some like the purest type of science. But the astronomer Martin Harwit has written a book pointing out that historically, almost all of the major breakthroughs in astronomy have come from new technical ideas and initiatives.

One of my favorite examples of science coming from good engineering is the history of the careful engineering study of noise—something my connections with Bell Labs has made me well aware of. J. P. Johnson was at Bell Labs when I first went there. He had looked into the source of noise in amplifiers. The result was a basic discovery, the basic thermal voltage fluctuations in a resistor, which were then named Johnson noise. For optimum radio communications, Karl Jansky built a steerable antenna to examine the direction and source of whatever radio noise might be present. He discovered radio waves coming from the direction of the center of our galaxy, initiating the exciting and very important field of radio astronomy. Our astronomers were rather slow in recognizing the potential of what Karl Jansky had discovered, and it was primarily people such as engineers and physicists experienced with radar who later developed this important field. I feel sure Jansky would have received a Nobel Prize if his discovery had been appreciated as it is now before he unfortunately died. He and his work inspired some of my own astronomical explorations. Somewhat later, Arno Penzias and Bob Wilson at Bell Labs were making further engineering studies of noise, with the still more sophisticated equipment of their day, and found microwave radiation left over from the "Big Bang," the initial explosion of the universe about 15 billion years earlier. What could be more basic or exciting science than discovering the origin of the universe? And this *was* recognized by a Nobel Prize.

Careful examination of things and perceptive exploration is required in both science and engineering, and history is full of the happy surprises this provides. The laser is now well known in such fields as communications, as a unique tool in medical operations, in dense storage and readout of information, in powerful cutting and welding techniques, and in precise measurements. But who would have thought such things as a tool for surgeons would come out of the examination of molecules by microwave spectroscopy—a field in turn resulting from radar engineering and development. Yet, this was indeed the laser's origin. And I know from firsthand experience that many world-famous physicists, well trained in quantum mechanics but without experience in electronic amplifiers and oscillators, just did not get the point or have the right intuitions about how a maser or a laser might work. Engineers knew very well the importance of amplifiers and oscillators and how they worked, but not many at that time were trained in the necessary quantum mechanics.

Again, in my view, engineering and science help each other grow, and I believe we must avoid boundaries between them and see that they are strongly interactive.

If we look in the direction of public policy, I believe we can all be delighted that the National Academy of Engineering and the National Academy of Sciences are working closely together in advising our government and others on policy matters. As science and technology steadily become more and more powerful, we need even more careful consideration of how they are used. Engineering has a larger and a more natural role than does science alone in considering how new science and discoveries can be and should be applied to practical human uses and for improving human life.

It is the responsibility of all of us to consider the sociology, the ethics, and the good but also sometimes the hazardous effects on humans and on our world that the many advances in technology produce. But because engineering is directed strongly towards the human use of new ideas, I believe engineers and engineering are in a particularly crucial position to help make appropriate decisions about the effects and appropriate use of our increasingly powerful technology. This is one of the reasons I am very appreciative of the National Academy of Engineering and its growing role in consideration of national and international policy. I am proud to be a member and very proud to receive the Founders Award.

NAE Calendar of Meetings

2000

5 December	NRC Governing Board Executive Committee
6 December	DARPA Prize Competition Workshop
9 December	NAE Committee on Membership Irvine, Calif.

2001

17 January	NRC Governing Board Executive Committee
22–23 January	Committee on Diversity in the Engineering Workforce
30 January	Committee on Engineering Education Irvine, Calif.
31 January	Membership Policy Committee Irvine, Calif.
5–6 February	NRC Governing Board Irvine, Calif.
7–8 February	NAE Council Irvine, Calif.
9 February	NAE National Meeting Symposium Irvine, Calif.
13 February	NRC Governing Board Executive Committee
18–24 February	National Engineers Week
20 February	Draper and Russ Prizes Dinner Presentation Union Station, Washington, D.C.
8 March	NAE Regional Meeting, Harvard University Cambridge, Mass.
13 March	NRC Governing Board Executive Committee
19 March	NAE Regional Meeting, Texas A&M University College Station, Tex.

All meetings are held in the Academies Building, Washington, D.C., unless otherwise noted.

Sixth Annual U.S. Frontiers of Engineering

Mark Maier from the Aerospace Corporation gave a presentation on battlefield management as part of the Systems Engineering session.

Robert Lucky, corporate vice president of applied research at Telcordia Technologies, Inc., talked about the future of information technology in his dinner address.

The systems engineering aspects of battlefield management, data mining and visualization, genomics and ethics, and the science and technology of nanotube-based materials were some of the exciting topics covered at NAE's sixth Frontiers of Engineering Symposium, held at the Beckman Center in Irvine, California, 14–16 September. The 100 engineers who attended this year's meeting learned about leading-edge engineering research and technical work in sessions on systems engineering, visual simulation and analysis, engineering challenges and opportunities in the genomic era, and nanoscale science and technology.

Themes that emerged from the systems engineering session, which covered the international space station, battle management, and software development, continued to resurface in other sessions throughout the symposium. The speakers in the visual simulation session amply demonstrated—through talks on physically based animation, data mining and visualization, and multiresolution methods for modeling, simulation, and visualization—that visual simulation is more than just pretty pictures. The four speakers in the genomics session covered the human genome project, the characterization of proteins in a small model genome, a bioengineering approach to understanding developments in molecular biology and genomics, and ethical questions generated by advances in genomics. The last talk set the stage for break-out session discussions on the merits and perils resulting from the development and application of genomic technologies. The symposium's concluding session on nanotechnology provided an introduction to this field with presentations on the synthesis, processing, and application of functional nanostructured inorganic particles; carbon-based nanotubes; and nanoscale semiconductor devices.

As with past Frontiers of Engineering symposia, one of the high points of the meeting was the dinner speech given on the first evening of the symposium. This year's speaker was **Robert Lucky,** corporate vice president for applied research, Telcordia Technologies, Inc., who spoke about the future of information technology. NAE member **Michael Corradini,** associate dean for academic affairs and professor of nuclear engineering and engineering physics at the University of Wisconsin, Madison, chaired the organizing committee and the symposium. Also serving on the organizing committee was NAE member **Patrick Hanrahan,** Canon USA Professor, computer science and electrical engineering departments, Stanford University. NAE Home Secretary **Dale Compton,** Lillian M. Gilbreth Distinguished Professor of Industrial Engineering at Purdue University, welcomed the participants to the meeting and provided background on the NAE, the National Academies, and the Frontiers program.

The NAE has been hosting an annual Frontiers of Engineering meeting since 1995. The meeting brings together some of the country's best and brightest engineers from industry, academia, and government at a relatively early point in their careers (participants are 30–45 years old). Frontiers provides an opportunity for the participants to learn about developments, techniques, and approaches at the forefront of fields other than their own, something that has become increasingly important as engineering has become more interdisciplinary. The meeting also facilitates the establishment of contacts and collaboration among the next generation of engineering leaders.

As one can imagine, developing a presentation for this audience is quite a challenge. While most of the participants have Ph.D.s in an engineering field, they are not necessarily experts in the fields being covered at the symposium. As a result, speakers are asked to give a brief overview of their topic—something at the cutting-edge of engineering—before discussing a specific technical problem, its solution, and its impact on research or industry. Speakers are also asked to talk about challenges and/or controversies in their fields, to summarize open research and/or applications questions, and to provide a view on what will be the exciting frontiers in the next 5–10 years. Typically, speakers embrace this challenge, with the result being that discussions are very lively and participants leave with some ideas for their own work, contacts, and a much greater appreciation for the engineering profession.

In February 2001, NAE will publish a symposium volume containing extended summaries of the presentations. An organizing committee, chaired once again by Michael Corradini, has begun planning for the next Frontiers meeting, to be held 13–15 September 2001 at the Beckman Center.

Funding for this year's U.S. Frontiers of Engineering Symposium was provided by the Defense Advanced Research Projects Agency, the Department of Defense (DDR&E-Research), NASA, Sandia National Laboratories, and numerous corporate sponsors.

For more information about the symposium series or to nominate an outstanding engineer to participate in the 2001 meeting, contact Janet Hunziker at the NAE Program Office at (202) 334-1571 or by e-mail at jhunzike@nae.edu

From the Foreign Secretary

This has been a very active period in the international arena. First of all, CAETS met in Beijing, China, on 13 October for the annual meeting of its governing board. The meeting was held immediately following the Chinese Academy of Engineering's International Conference on Engineering and Technological Sciences 2000, where NAE President **Wm. A Wulf** gave a talk on "Challenges for Computing and Information Technology in the Twenty-First Century." During the board meeting, academies of engineering from Korea, Croatia, Slovenia, and Uruguay were elected to membership, bringing the total number of CAETS member academies to 26. The board approved CAETS incorporation in the District of Columbia in order to expand its opportunities for fundraising and contracting as opportunities and needs arise. It also approved a new set of bylaws with provisions for a council of all member academies and a board of directors with four officers and four additional directors. This structure is expected to give CAETS greater flexibility in fostering collaboration and international meetings.

The current plan for upcoming CAETS convocation locations is Finland in 2001, the United States in 2003, Australia in 2005, and Japan in 2007. CAETS Council meetings will be held in the Czech Republic in 2002 and in Norway in 2004. Representatives from Canada suggested that CAETS undertake a multilateral study on climate and global energy strategy, and this opportunity is under study. Further actions are under way to find a way to bring Germany, with its many engineering academies, into CAETS, as well as Russia. The possibility of regional Frontiers of Engineering meetings was discussed and there seemed to be support, but many academies have very limited operating budgets and few outside opportunities to raise additional funds.

After the CAETS meeting, there was a meeting in Jakarta sponsored by the Indonesian Academy of Sciences with the interesting title, "Fourth Annual Meeting of the Academies of Science, Engineering and Technology and Similar National Organizations in the Southeast Asian Region and Sister Organizations from ASEAN Dialogue Partners." This event was mostly attended by science academies, but the NAE had been invited and we thought it would be useful to attend. Academies from Singapore, Japan, China, Brunei, India, Australia, and Malaysia attended. The Indonesians were gracious hosts and the meeting provided an opportunity to discuss international issues. Professor Yves Quere, president of the Inter Academy Panel (IAP), attended and explained their mission and the need for collaboration among all academies—science, engineering and medicine—to help solve the world's problems. The IAP has chosen four initial themes: health in developing countries, education in science, capacity building in academies, and science in the media. Much of this is similar to programs in the NRC, the NAE, and CAETS. IAP meetings are held annually, and next year's will be held in Malaysia. A follow-up meeting to the Tokyo meeting last year on "Transition to Sustainable Development" is planned for 2003.

The NAE Annual Meeting in October was highlighted by at least two items of international interest. First, the NAE signed its first memorandum of understanding with another CAETS academy. NAE President Bill Wulf and Song Jian, president of the Chinese Academy of Engineering, signed the memorandum in a formal ceremony attended by many of our Council. The document indicates our interests in working together on studies and visits and describes responsibilities for financing these activities within each country.

Second, the Annual Meeting also brought together several visiting foreign associates who helped celebrate the election of 8 new foreign associates, maintaining the total number at 150. The annual Foreign Secretary's breakfast provided an opportunity for foreign associates to meet and discuss items of interest. This meeting was also attended by Bill Wulf and executive officers of the NAE, NRC, and the Academies' Office of International Affairs.

The first Japan-America Frontiers of Engineering (JAFOE) symposium was held in Nara, Japan, 2–4 November, and it was a huge success. The Japanese sponsor, the Japan Science and Technology Corporation, indicated that they would like to see the program continued in the future and would be willing to sponsor the Japanese costs. As in all international Frontiers meetings, guests from other countries were invited to attend, and this year the Chinese and Korean Academies of Engineering each nominated and sent three young researchers to the meeting. Four research areas were discussed in the symposium: earthquake engineering, design and integration of functional inorganic materials, manufacturing, and biotechnology. The sessions were lively and the participation suffered little from being held in English. The second JAFOE symposium will be held in the United States next year at the Beckman Center in Irvine, Calif., 29 November through 1 December.

NAE and the Nobel Prize in Physics

The Nobel Prize in Physics was awarded 10 October to two foreign associates and one member of the NAE. **Zhores I. Alferov** and **Herbert Kroemer** share one half of the prize with the other half going to **Jack S. Kilby**. Their citation reads: "The researchers' work has laid the foundations of modern information technology, IT, particularly through their invention of rapid transistors, laser diodes, and integrated circuits (chips)." This award brings the number of NAE members who have won the Nobel Prize in Physics to 10: 7 members and 3 foreign associates. In 1956, **John Bardeen**, who has since passed away, shared the physics prize with William Shockley and Walter Brattain for their researches on semiconductors and their discovery of the transistor effect. **Charles Townes**, Nicolay Basov, and Aleksandr Prokhorov shared the physics prize in 1964 "for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle." Four years later, **Luis Alvarez** was the sole winner of the prize "for his decisive contributions to elementary particle physics, in particular the discovery of a large number of resonance states, made possible through his development of the technique of using hydrogen bubble chamber and data analysis." **John Bardeen** won his second physics prize in 1972, shared with Leon Cooper and J. Robert Schrieffer for "their jointly developed theory of superconductivity." In 1973, there were three prize winners, and two of them, **Leo Esaki** and **Ivar Giaever,** were cited independently "for their experimental discoveries regarding tunneling phenomena in semiconductors and superconductors." Robert Wilson and **Arno Penzias** won the prize in 1978 "for their discovery of cosmic microwave background radiation." **Nicolaas Bloembergen** shared the physics prize in 1981 with Arthur Schawlow "for their contribution to the development of laser spectroscopy."

First Japan-America Frontiers of Engineering

Participants at the first Japan-America Frontiers of Engineering Symposium held in Nara, Japan.

The first Japan-America Frontiers of Engineering Symposium (JAFOE) was held at the Nara Prefecture New Public Hall in Nara, Japan, 2–4 November. With the expansion of the Frontiers program to Japan, there are now two bilateral meetings in addition to the U.S. Frontiers of Engineering symposium held every September. Like the Frontiers meeting with Germany, there were about 60 participants, with 30 engineers ages 30–45 from each country. Three observers each from South Korea and China also attended.

The goal of the Frontiers program is to bring together emerging engineering leaders in a forum where they can learn about leading-edge developments in a range of engineering fields, thereby facilitating an interdisciplinary transfer of knowledge and methodology. Through both formal sessions and informal discussions, the meetings have proven an effective mechanism for the establishment of cross-disciplinary and cross-sector contacts among future engineering leaders. In the case of the bilateral Frontiers, there is the added dimension of helping build cooperative networks of younger engineers that cross national boundaries.

NAE member **Robert H. Wagoner,** Distinguished Professor of Engineering, department of materials science and engineering, Ohio State University, and Yasutaka Iguchi, professor and vice director, New Industry Creation Hatchery Center, Tohoku University, cochaired the organizing committee and the symposium.

The four topics covered at the meeting were earthquake engineering, design and integration of functional inorganic materials, manufacturing, and biotechnology. Presentations, typically given by two Japanese and two Americans in each of the four areas, covered such topics as applications of new technologies in geotechnical earthquake engineering, atomic structure control of electronic ceramic thin films, sub-50-nanometer lithography, and drug delivery technologies. In addition to excellent presentations and animated question and answer periods (that were not impeded by the use of English), other highlights of the meeting included poster sessions that allowed each participant to talk about his or her technical work or research; tours of historical sites in Nara, the ancient Japanese capital; a Noh performance; and technical visits to ATR Institute, an information technology research facility, Sekisui, and Sharp Corporation. Mr. Shoichiro Yoshida, president of Nikon Corporation, gave the dinner address on the first evening of the symposium.

The JAFOE symposium was organized in cooperation with the Engineering Academy of Japan and the Japan Science and Technology Corporation (JST). Funding was provided by JST, the National Science Foundation, and the Office of Naval Research. Based on the success of this first bilateral Frontiers meeting with Japan, plans are under way for a second JAFOE meeting in the United States, November 29–December 1, 2001, at the Beckman Center. An organizing committee for the 2001 meeting, chaired by Robert Wagoner and Hideaki Matsubara, deputy director, Japan Fine Ceramics Center R&D Lab, met in Nara and is planning a program in the areas of pervasive computing, manufacturing, biotechnology, and synthesis and applications of nanomaterials.

For more information about this activity, contact Janet Hunziker in the NAE Program Office at 202/334–1571 or by e-mail at jhunzike@nae.edu.

In Memoriam

JAMES J. CARBERRY, 74, professor emeritus, University of Notre Dame, died on 27 August 2000. Dr. Carberry was elected to the NAE in 1989 for fundamental contributions to chemical reaction engineering and heterogeneous catalysis.

RALPH E. FADUM, 87, dean emeritus, School of Engineering, North Carolina State University, died on 12 July 2000. Dr. Fadum was elected to the NAE in 1975 for his contributions as a civil engineer, educator, consultant, researcher, and author; and for his pioneering work in soil mechanics and foundation engineering.

ROBERT R. GILRUTH, 86, retired director, NASA Manned Spacecraft Center, died on 17 August 2000. Dr. Gilruth was elected to the NAE in 1968 for the development and use of satellites and for aircraft design and testing in subsonic, transonic, and supersonic speed ranges.

LAWRENCE H. HODGES, 80, technical affairs consultant, died on 27 August 2000. Mr. Hodges was elected to the NAE in 1985 for his long-term pursuit of excellence in the development, application, and promulgation of practical standards in the United States and international engineering communities.

WILLIAM A. NIERENBERG, 81, director emeritus, Scripps Institution of Oceanography, University of California, San Diego, died 10 September 2000. Professor Nierenberg was elected to the NAE in 1983 for outstanding engineering and scientific contributions in the field of oceanography with particular application to deep ocean operations.

ALEX G. OBLAD, 90, distinguished professor of fuels, emeritus, University of Utah, died on 19 September 2000. Dr. Oblad was elected to the NAE in 1975 for leadership in the development of important commercial hydrocarbon and petrochemical processes.

A. ALAN B. PRITSKER, 67, retired CEO, Pritsker Corporation, died on 24 August 2000. Dr. Pritsker was elected to the NAE in 1985 for the design and development of simulation languages and network techniques and their applications in improving industrial productivity.

ARCHIE W. STRAITON, 92, professor emeritus, the University of Texas at Austin, died on 22 July 2000. Dr. Straiton was elected to the NAE in 1976 for contributions to the understanding of ultra-high-frequency radiowave propagation.

PETER SWERLING, 71, president, Swerling, Manasse & Smith, Inc., died on 25 August 2000. Dr. Swerling was elected to the NAE in 1978 for contributions to detection and estimation of random processes and their applications to radar systems.

National Research Council Update

Advanced Engineering Environments

Advanced engineering environments (AEEs)—integrated systems of simulation, computing, and telecommunications technologies—will someday enable teams of researchers, technologists, designers, manufacturers, suppliers, customers, and other users scattered across a continent or the globe to develop new products and carry out new missions with unprecedented effectiveness.

Several government entities, including NASA, are involved in AEE research and development in the United States. NASA requested the NRC's Commission on Engineering and Technical Systems, through its Aeronautics and Space Engineering Board, to undertake a study of AEEs, paying particular attention to NASA and the aerospace industry. The study was carried out in two phases: Phase 1 concentrated on the near-term steps the federal government, industry, and academia could take to enhance the development of AEE technologies and systems with broad application in the U.S. engineering enterprise; and Phase 2 focused on the long-term potential of AEE technologies and systems.

The Phase 1 report was issued in 1999. Now the report of Phase 2 has been published, describing the organizational and procedural changes that government, industry, and academic organizations can make to take advantage of existing and soon-to-be-available technologies. In most cases, the committee determined that issues relevant to NASA and the aerospace industry were also relevant to other organizations involved in the development or use of AEE technologies or systems. Therefore, although some recommendations specifically call for action by NASA, the report was written with a broad audience in mind. Included in its recommendations are the following:

- Government, industry, and academia should seek consensus on interoperability standards.
- R&D by the federal government on the visualization of engineering and scientific data should focus on long-term goals that go beyond those of ongoing R&D by industry.
- Federal agencies involved in AEE R&D should be more aggressive in forming a national partnership with industry and academia to develop AEEs that offer seamless, end-to-end engineering design capabilities that encompass the entire life cycles of products and missions.
- Advanced Internet technologies and applications are one of the keys to developing AEEs.
- Successful implementation of AEEs by NASA will require sustained leadership and commitment, adequate funding, and a cohesive plan that includes all NASA centers.

Design in the New Millennium: Advanced Engineering Environments: Phase 2 is the report of the Committee on Advanced Engineering Environments. The report can be purchased or read online at www.nap.edu/catalog/9876.html.

Publications of Interest

The following publications result from the program activities of the National Academy of Engineering or the National Research Council. Except where noted, each publication is for sale (prepaid) from the National Academy Press (NAP), 2101 Constitution Avenue, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at http://www.nap.edu or by phone at (800) 624–6242. *(Note: Prices quoted by NAP are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book ordered and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Biobased Industrial Products: Research and Commercialization Priorities. Discusses the concept of the biorefinery and outlines proven and potential thermal, mechanical, and chemical technologies for conversion of natural resources to industrial applications; illustrates the developmental dynamics of biobased products through existing examples, as well as products still on the drawing board; and identifies priorities for research and development. Paperbound, $35.00.

Design in the New Millennium: Advanced Engineering Environments: Phase 2. Advanced simulation, computing, and telecommunications technologies will someday enable teams of widely scattered researchers, designers, manufacturers, and customers to develop new products and carry out new missions with unprecedented effectiveness. This report describes organizational and procedural changes that government, industry, and academic organizations can make to take advantage of existing and soon-to-be-available technologies. Paperbound, $18.00.

The Digital Dilemma: Intellectual Property in the Information Age. Presents the multiple facets of digitized intellectual property, defining terms, identifying key issues, and exploring alternatives. Follows the complex threads of law, business, commercial incentives, and information rights, and proposes research and policy recommendations as well as principles for policymaking related to intellectual property rights. Paperbound, $42.95.

Frontiers of Engineering: Reports on Leading Edge Engineering from the 1999 NAE Symposium on Frontiers of Engineering. Presents extended summaries of the presentations given at the October 1999 symposium on topics that include the human genome, engineering novel structures, and energy for the future and its environmental impact. Paperbound, $31.00.

Making IT Better: Expanding Information Technology Research to Meet Society's Needs. Highlights the fundamental importance of research to ensure that information technology, a critical underpinning to our nation's success, keeps pace with society's expanding needs. Forthcoming. Paperbound, $29.95.

Nature and Human Society: The Quest for a Sustainable Future. Over the next hundred years, two-thirds of all life forms on Earth face extinction, largely because of uncontrolled development by humans. In this summary of the second National Forum on Biodiversity, the world's leading experts in the field describe the crisis ahead and the need to build a sustainable world in which animals, plants, fungi, microorganisms, and people can coexist harmoniously. Hardcover, $79.95.

Review of the Research Program of the Partnership for a New Generation of Vehicles: Sixth Report. Examines the overall adequacy and balance of the PNGV research program. Discusses ongoing research on fuels, propulsion engines, and emission controls, and reviews the USCAR partners' progress on PNGV concept vehicles for 2000. Paperbound, $32.00.

Trust in Cyberspace. Provides an assessment of current state-of-the-art procedures for building trustworthy networked information systems, proposing directions for research in computer and network security, software technology, and system architecture. Assesses current technical and market trends in order to better inform public policy as to where progress is likely and where incentives could help. Hardcover, $44.95.