The
BRIDGE

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Editorial

George Bugliarello is chancellor, Polytechnic University, and interim editor-in-chief of The Bridge.

Frontiers of Engineering

The tragic events of September 11 have placed a unique and urgent responsibility on the engineering community to bring our knowledge and skills to bear to help protect our fellow citizens from further attacks. We must also provide a vision and a commitment to help alleviate the poverty and social imbalances that are the endemic incubators of unrest in the world. In the next issue of *The Bridge* we will address some aspects of this multidimensional challenge.

The present issue (in preparation before September 11) focuses on papers prepared for the 2001 Frontiers of Engineering Symposium, which was scheduled for September 13–15 but had to be canceled. Every year since 1995 the symposium has brought together 100 future leaders in engineering to attend presentations on cutting-edge research and technologies in different areas of engineering. In the past seven years, a wide range of topics has been addressed. The papers presented at the symposia, which are collected and published annually by the National Academy Press, offer an inspiring cross section of new directions in engineering. The symposium in 2000, for example, covered systems engineering, visual stimulation and analysis, engineering challenges and opportunities in genomics, and nanoscale science and technology.

The 2001 symposium was organized around four themes: extreme aerodynamics from mega to micro, city systems, wireless communications, and technology and the human body. We have chosen one from each area for expansion and publication in this issue of *The Bridge*. All of the papers will be available in the annual proceedings.

If a Frontiers of Engineering symposium had been held 50 years ago, it would have had, by necessity, a much narrower scope. At that time, the topics in this issue, extreme aerodynamics, ubiquitous interpersonal wireless communications, agent-based simulations for dealing with complex infrastructural interdependencies, and bioengineering, were not even on the radar screen of the engineering profession.

It will be interesting to see where the topics of the 2001 symposium will have led us 50 years from now. For instance, the application of micro-aerodynamics—the extreme aerodynamics discussed in the paper by Fearing—might have many revolutionary applications. Micro-aerodynamics could be extended beyond microfliers to flying machines with the kind of capabilities for which we envy insects and even to the study of microclimate phenomena and microflows over the leaves of plants and, hence, to agriculture. The interdependencies and complexity of civil infrastructural systems will continue to increase, and the need for powerful tools to plan and control them, the subject of Heller's paper, was brought vividly to the fore by the events of September 11. Wireless communications, the topic of the paper by Pottie, are likely to become so ubiquitous, powerful, and flexible as to further transform civilian life as well as military affairs. Again, the events of September 11 have demonstrated their importance in emergency situations. And, just as CT scanners and MRIs have revolutionized diagnostics, the reengineering of the paralyzed nervous system, the subject of Peckham's paper, will have extraordinary therapeutic implications, reinforcing the view of engineering as the continuation of biology by other means. There can be little question that the combination of engineering and biology will make the boundary between biological organisms and machines an area rich in promise for the creation of new technologies.

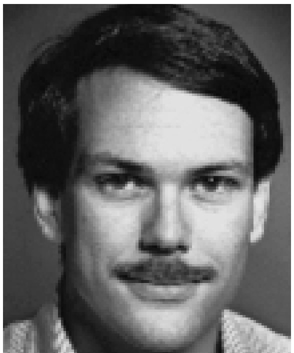
The imperative for engineering is to expand these and other emerging frontiers with an acute awareness of their impacts on our lives. This immense task has become more important and more urgent since the September 11 tragedy.

George Bugliarello

Toward Micromechanical Flyers

Ronald S. Fearing

Microrobots could be two to three orders of magnitude cheaper than conventional trash-can-size robots.



Ronald S. Fearing is a professor in the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley.

In this paper I describe some of the microflyers being developed around the world and the engineering challenges they present. Advances in the late 1980s in microelectromechanical systems (MEMS), especially the surface micromachined electrostatic micromotor of Fan et al. (1988), inspired roboticists to think small. In 1987, Flynn proposed building inexpensive, disposable, autonomous milligram (mg)-mass microrobots that could be deployed in massive swarms. In my back-of-the-envelope calculations, the cost per unit would be $1.00 to $10.00, perhaps two to three orders of magnitude cheaper than conventional trash-can-size mobile robots. In this new paradigm, huge numbers of moderately intelligent and robust microrobots could perform tasks, such as searching an area, more effectively than a single expensive macrorobot.

Research on mobile microrobots is being done on legged devices (Eberfors et al., 1999; Yeh et al., 1996) and flying devices (Crary et al., 1992; Shimoyama et al., 1994). Legged devices can be made statically stable, and hence easy to control, but path planning can be difficult for an ant-sized device with six 5-millimeter (mm) high legs. Flying devices have much more difficult power and control requirements, but avoiding obstacles while flying around a room seems easier than negotiating a shag carpet with six 5-mm high legs.

For high speed, flying is the way to go. Small flying insects, such as the hoverfly, can reach peak speeds of 10 meters per second, (about 1,000 body lengths per second). Rotary or flapping wings provide hovering capability but drastically increase power requirements. For example, the flyer reported in Flynn (1987) was a fixed-wing device with a 12-centimeter wingspan that weighed 80 mg. The device required only 5 watts per kilogram (W/kg) to fly using a propeller without flapping its wings. (It should be noted that this device was powered by a rubber band and had no control electronics.) By comparison, flapping flyers require 100 to 200 W/kg. The extra power of flapping flight greatly improves maneuverability.

Perhaps surprisingly, small, subcentimeter flyers may turn out to be easier to construct than larger flyers, not because the aerodynamics are easier, but because the actuator power density increases with higher operating frequencies. In addition, the surface area-to-volume ratio improves for small devices. Thus, small flyers might be driven by solar cells. With piezoelectric actuators running in resonance at the wing beat frequency, power density is proportional to frequency. In addition, at smaller scales, one can generally avoid conventional joints and bearings, which are heavy, and use flexural joints, which are lighter and scale down well in size.

Designing a micromechanical flyer, a device with maximum dimensions of 25 mm and a mass of 100 mg, for example, is a challenge on many fronts—aerodynamics, actuation, transmission, power supply, sensing, control algorithms, compact low-power electronics, and flight behavior. As far as I know, no flyer smaller than the Caltech microbat has flown freely. Only the 10 gram Caltech microbat ornithopter (Figure 1) has flown under its own power with passive stabilization.

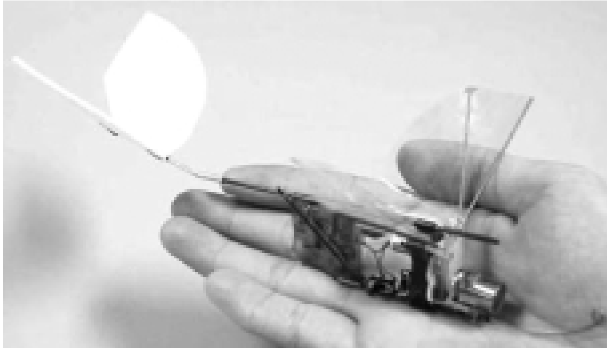


FIGURE 1 Caltech microbat.
Source: Pornsin-Sirirak et al., 2001.

FIGURE 2 SRI flapper.
Source: SRI, 2001.

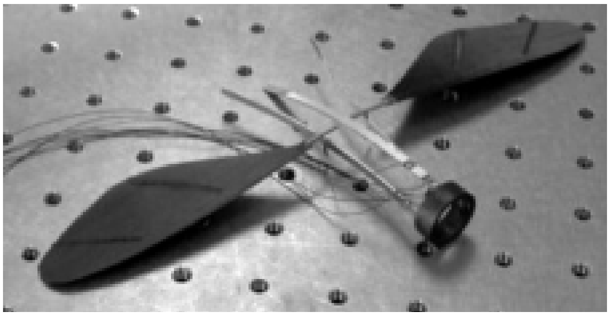


FIGURE 3 Vanderbilt University mesoscale flying robot.
Source: Cox et al., 1999.

Ornithopter Micro Air Vehicles

Several groups, notably Caltech, SRI, and Vanderbilt, have developed components for small bird-size ornithopters. Interestingly, all of these designs use only 1 degree of freedom wings and rely on passive or coupling mechanisms to control wing rotation. The Caltech design (Figure 1) uses a standard direct current (DC) motor and gear box. The SRI device uses electrostrictive polymer actuators (Figure 2). The Vanderbilt device uses piezoelectric actuators (Figure 3).

Rotary and Flapping Wing Microflyers

Based on our macroscale experience, we assume that a rotary wing device with fixed angle of attack would be easier to fabricate than a beating wing

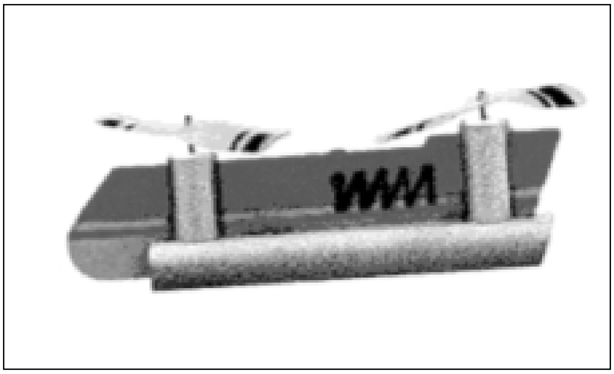


FIGURE 4a Institut für Mikroteknik Mainz's uncontrolled helicopter, length 24 mm, mass 0.4 grams.
Source: IMM, 2001.

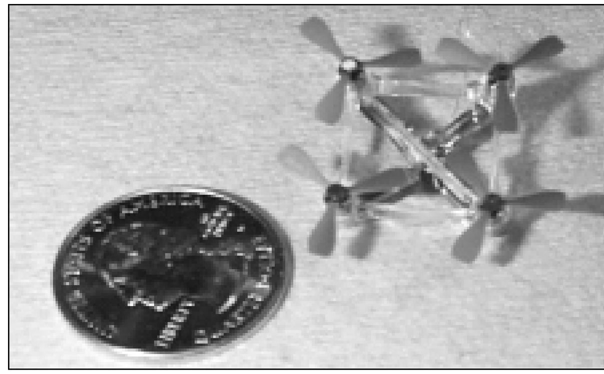


FIGURE 4b Mock-up of the Stanford Mesicopter with four 1.5-cm rotors and a mass of 3 grams.
Source: Stanford University, 2001.

device. We are right—to a point. The assumption doesn't hold up, however, when we reach the lower limit of magnetic motor size, which is currently 1.9 mm diameter, 5.5 mm length, and 91 mg mass (Faulhaber Group, 2001). Mock-ups of helicopters using these motors have been constructed by Institut für Mikroteknik Mainz in Germany (Figure 4a) and Stanford University (Figure 4b). Keeping the mass of the device under 100 mg will require more compact actuators. I expect that shrinking bearings further to create an efficient, high energy density, submillimeter magnetic motor will be difficult. Thus, in terms of miniaturization, one is encouraged to think of beating wings rather than rotary wings. Flapping wings can change the direction of applied torques in a wing beat, potentially improving maneuverability. A mock-up of the Berkeley micromechanical flying insect (MFI) is shown in Figure 5.

Aerodynamics

As a design target for the MFI, we chose the blowfly (*Calliphora*), which has a mass of 100 mg, a wing length of 11 mm, a wing beat frequency of 150 Hz, and actuator power of about 8 milliwatts (mW). At this size scale, our current understanding of nonsteady-state aerodynamics comes from experimental observations of real insects and kinematically similar mock-ups (Dickinson et al., 1999; Ellington et al., 1996).

The Robofly apparatus (Dickinson et al., 1999) consists of a two-winged system driven by three stepping motors, which can closely mimic the stroke kinematics of a fruit fly (*Drosophila*) or other arbitrary kinematics. Strain gauges are used to measure instantaneous wing forces, and the integral of forces around a closed wing beat cycle can be measured to determine net flight forces. A Robofly running with a wing beat of 1/6 Hz in oil has the same Reynold's number as a *Drosophila* with a wing beat of 220 Hz in air. Flow was visualized using air bubbles in an oil tank and particle image velocimetry.

The Robofly apparatus has enabled Dickinson and colleagues to identify the three key aerodynamic mechanisms used by insects: delayed stall and wake capture (Figure 6) and rotational circulation (Figure 7). Dickinson et al. (1999) found wing trajectories that generate peak lift forces of four times the equivalent insect weight. Due to rotational lift, the timing of an equivalent of a backspin motion at the bottom of the wing stroke can change the net lift from positive to negative. The second key mechanism is the significant

FIGURE 5 Mock-up of the Berkeley micromechanical flying insect (wingspan 25 mm and final mass target 100 mg).

force generated by wake capture at the top and bottom of the wing stroke. Applying these results to the wing kinematics of the MFI, we realized that a rapid wing rotation of 90 degrees is necessary before the end of the downstroke to create adequate lift.

Thorax Design

We know that insect flight at the centimeter scale requires both large stroke amplitude and large wing rotation (Dickinson et al., 1999). *Drosophila* has a wing stroke of 160 degrees combined with wing rotation of more than 90 degrees (*Calliphora* has similar kinematics). Wing rotation is the challenging part of the design. The insect thorax has a complicated arrangement of linkages and cams, which is not yet fully understood and is likely to be too difficult to replicate (Nachtigall et al., 1998). The electromechanical design of the thorax poses some interesting challenges. The actuators combined with the wing transmission should weigh less than 50 mg, and provide 10 mW of mechanical power to a wing being driven in flapping and rotation at 150 Hz with large amplitudes.

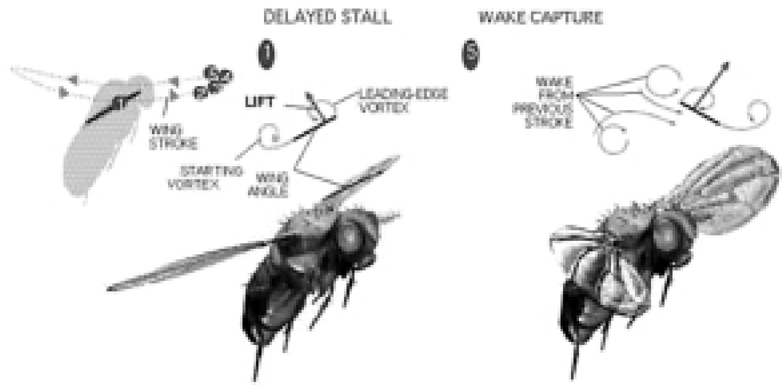


FIGURE 6 Delayed stall and wake capture effects.
Source: Dickinson, 2001.

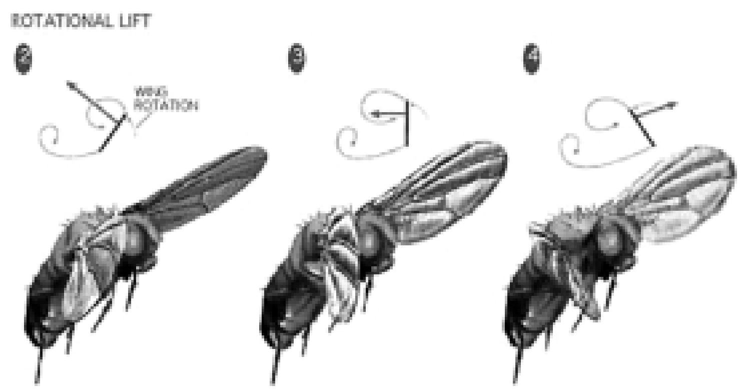
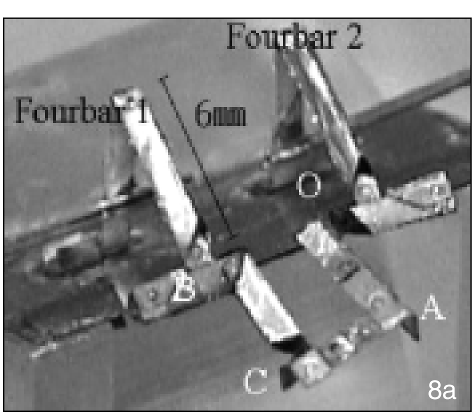
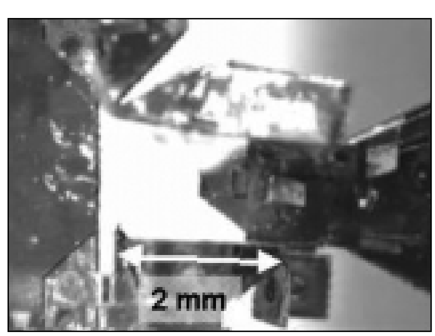


FIGURE 7 Lift due to wing rotation and ends of stroke.
Source: Dickinson, 2001.

For actuators, we use piezoelectric unimorphs, which have a DC displacement of about 1 degree. Two stages of mechanical amplification using planar fourbars bring the output motion at DC to 50 degrees. Separate actuators drive the leading and trailing edges of a differential assembly, as shown in Figure 8a,b. The thorax is designed to be run in resonance with a quality factor (Q) of 2.5. A higher Q would reduce the response speed of the wing to controlling rotation; a lower Q would require an even higher transmission ratio. It turns out that even a very low wing inertia is not sufficient for proper operation; wing inertia ratios must be chosen for dynamic decoupling of the differential. The





8b

FIGURE 8a MFI thorax for driving one wing consisting of a pair of fourbars driving a wing differential mechanism, OACB. 8b Detail of compact, low inertia, wing differential.
Source: Yan et al., 2001.

overall thorax kinematics is a closed chain manipulator with 17 joints and 2 degrees of freedom. For light weight and strength, the structure is assembled from a 12.7-micron stainless steel sheet folded into hollow beams with polyester flexure joints between links.

Summary

Research on micromechanical flyers has led to an understanding of how to generate high-frequency, high-amplitude wing motions in a low-mass, compact device. The challenges ahead will be to integrate sensing and control devices into this inherently very unstable, but potentially high-performance, flying device. Taking our inspiration from real insects and our tools from MEMS, we will work on integrating optical flow and gyroscopic sensing on the MFI to control attitude and bring the device closer to its first free flight.

Acknowledgments

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Interdependencies in Civil Infrastructure Systems

Miriam Heller

Integrated information systems can increase accuracy, improve services and products, reduce capacity needs, make utilization more efficient, and reduce costs.

Miriam Heller is program director of the Infrastructure and Information Systems Program at the National Science Foundation.

Information systems hold the key to the efficient planning, design, construction, operation, maintenance, and retirement of our nation's very valuable civil infrastructure assets. Information systems are already being integrated into infrastructure operations to exploit new technologies, compensate for capacity limitations, address regulatory changes, increase efficiency, and protect against natural, accidental, and deliberate threats. Integrated information-infrastructure systems drive traffic signals and variable message signs on roadways and bridges, monitor potable water quality at treatment plants, pump water and wastewater, and activate switches in telecommunications systems that command transportation and water networks. All of these capabilities are enabled by energy and power infrastructures, which, in turn, depend on even more information infrastructure. In short, information systems can make or break civil infrastructure.

Integrated information systems have substantially improved unit-level and component-level operating efficiencies in transportation, water, telecommunications, and power infrastructures, just to name a few. The benefits include increased accuracy, expanded and improved services and products, reduced capacity needs, higher utilization, and lower costs. Theory suggests that further efficiencies are achievable by integrating information systems at increasingly higher levels: the subsystem level, the system level, and even across infrastructure systems. History suggests, however, that further efficiencies might be difficult to realize because of trade-offs with induced vulnerabilities.

The longer we ignore these problems, the more they will create new and exacerbate old vulnerabilities.

As the automation of infrastructure systems increases, system behaviors are becoming complex beyond comprehension and more far-reaching than was ever anticipated. Interdependencies can reverberate perturbations globally. In 2001, for example, the real-life restructuring of California's electricity industry demonstrated linked and unexpected effects. Fuel production, refining, and distribution were disrupted, sometimes cutting off fuel supplies to the very plants that should have been generating their electricity. Interruptions in water distribution affected the state's agribusiness. Soaring wholesale power prices had rippling regional effects. In Washington state, salmon-protection and air-quality regulations had to be relaxed and aluminum mills shut down. Idaho farmers curtailed potato production to exploit Idaho Power Company's electricity buy-back program.

This paper focuses on the tension between the need to push our civil infrastructure systems to higher levels of efficiency and competitiveness and the need to ensure minimum levels of service, reliability, and security, even under critical conditions. To set the scene, some recent history is given, and infrastructure systems are described in terms of their performance, interdependencies, and vulnerabilities. This is followed by a description of some emerging frameworks that promise to capture these "systems of systems" and their interdependencies. A case study is presented highlighting the benefits of exploiting interdependencies, and research challenges are identified.

Infrastructure Interdependencies

Infrastructure interdependencies appeared on the radar screens with Presidential Decision Directive 63 (PDD-63) on Critical Infrastructure Protection. Prompted by the Oklahoma City bombing in 1995 and the 1996 Defense Science Board Task Force on Information Warfare, PDD-63 was the culmination of a 15-month study by the President's Commission on Critical Infrastructure Protection, which revealed the rapidly growing capability of exploiting energy, banking and finance, transportation, vital human services (water, wastewater, and health services), and telecommunications infrastructures, especially through digital infrastructures (PDD63, 1998). The directive acknowledged that our national and economic security depend on the critical infrastructures and information systems that support them. To ensure their reliability and protection, committees were established for each infrastructure sector and paired with their agency counterparts to study sector-specific problems. These initiatives have focused on protecting information systems against malicious intrusions (cyber attacks) that could cause the banking, finance, power systems, and other critical infrastructures to fail.

Infrastructure systems are also vulnerable to myriad stresses and failures as a result of everyday interdependencies, insufficiencies, and inefficiencies. Cascading power blackouts in the United States in July and August 1996 cost an estimated $1.5 billion, including related infrastructure and environmental impacts (Amin, 2000). On a grander scale, recent estimates of the annual cost to the U.S. economy from non-cyber power disturbances exceed $119 billion, most of which is related to disruptions to discrete manufacturing and electricity-dependent utilities (Lineweber and McNulty, 2001). Traffic congestion costs the nation an additional $78 billion annually in 4.5 billion hours of extra travel time and 6.8 billion gallons of fuel idled away in traffic jams (TTI, 2001).

The longer we neglect these problems, the more they will create new and exacerbate old infrastructure vulnerabilities. The estimated cost of maintaining the *status quo* of existing infrastructure systems is

$1.3 trillion over the next five years (ASCE, 2001). Although this figure seems high at first glance, it seems reasonable considering that the total U.S. investment in infrastructure is more than $7 trillion (CERF, 1997).

Natural interventions test the robustness and reliability of infrastructure design. The cost of earthquakes averages $4.4 billion per year (FEMA, 1999). Another intervention, space weather, was the culprit in 1998. When the Galaxy 4 satellite's attitude control system failed, radio, television, pager, bank machine, and other satellite-linked services across North America were disrupted. As an example of the cost, two pager companies that did not have backup systems in place lost $5.8 million. Indirect and intangible costs included lost credit card sales, missed market trades, inability to contact doctors and emergency medical services, and many others.

The tragedies of September 11, 2001, have given us new data on the costs of physical infrastructure catastrophe, their interdependencies, and their resiliency. In the first weeks after the attacks, losses to the air transportation industry were estimated at $320 million per day. The direct and indirect costs of the closure of Reagan National Airport, the drastic decrease in tourism, lower consumer spending, and bankruptcies will probably never be tallied. The disaster relief package of $40 billion from the federal government provides, at best, a lower bound. The structural changes to the U.S. economy and the American life style have yet to be fully realized, much less assessed.

As a result of these events, questions about how to manage the life cycle (i.e., the design, construction, operation, maintenance, and retirement) of civil infrastructure systems and their digital infrastructure adjuncts have become urgent.

- What methods and tools can capture, clarify, and predict the complex behaviors and interdependencies of infrastructure systems?
- How can maximal efficiency during normal operations be balanced with resiliency, sustainability, and minimal vulnerability to common and catastrophic failures?
- Which measures of performance adequately capture system(s) complexity?
- Who are the decision makers and stakeholders, and what are their goals and objectives?
- How can risk and uncertainty be incorporated into the design and management of infrastructure systems?

Even before September 11, these questions had taken on greater urgency as infrastructure systems were being pressed to meet or surpass the levels of efficiency of the systems that create the demand for their services (e.g., just-in-time manufacturing, e-commerce sales and procurement, and overnight delivery). The vulnerabilities intrinsic to interdependent, slack-free, deteriorating, or externally threatened systems must be understood, predicted, sensed, and engineered to meet multiple performance measures. Optimizing these systems for normal conditions without considering the costs, risks, and uncertainties of "abnormal" conditions would be shortsighted and even dangerous. But even the horrors of September 11 must not blind us to the ongoing need for investing in the design and operation of infrastructures that can, and do, cost billions of unnecessary dollars and lead to many deaths every year.

Structural changes to the U.S. economy and the American life style have yet to be fully realized.

Emerging Frameworks

Developing a model of a single infrastructure system, with its own patterns of use, its interactions with associated natural and economic systems, and its reactions to technological and natural interventions, poses serious challenges. Many infrastructure systems (e.g., power, transportation, and telecommunications) are complex adaptive systems (CASs), that is, their collective, systemic behavior is emergent (i.e., it follows patterns that result, yet are not analytically predictable from, dynamic, nonlinear, spatiotemporal interactions among a large number of components or subsystems [Coveney and Highfield, 1995]). Because a CAS is greater than the sum of its parts, the system can only be described at levels higher than the components.

The size and frequency of electricity disturbances, for instance, obey the power law, a characteristic of complex systems at the critical edge between order and chaos (Amin, 2001). CASs are adaptive in that the capabilities of components and decision rules change over time in response to interactions with other components and external interventions (Gell-Mann, 1994).

Despite the challenges, modeling systems of infrastructure systems, whether CAS or not, is necessary for optimal life-cycle management of civil infrastructure systems. Much remains to be done to develop models and merge individual models of coupled systems, including formalizing theories and conceptual frameworks for meta-infrastructure systems to support them. Although new methods and tools for individual infrastructure system models have been evolving, fewer attempts have been made, and even fewer successes attained, at modeling meta-infrastructure systems.

Rinaldi et al. (2001) have proposed a general framework for characterizing infrastructure interdependencies. The framework identifies infrastructure systems as CASs and provides details for developing agent-based simulations (ABSs) of complex systems. The authors identify six dimensions of infrastructure interdependencies: infrastructure environment, coupling, response behavior, failure types, infrastructure characteristics, and state of operation. Analyzing infrastructure in these terms yields new insights into infrastructure interdependencies. They also identify four *types* of interdependencies: physical, cyber, logical, and geographical. In a physical interdependency, the states of two infrastructures (e.g., a coal-transporting rail network and a coal-fired electrical plant that supplies the power to that rail network) depend on the material output of both. Other interesting issues are also raised, including requirements for an information architecture; data capture, storage, and privacy; and model metrics.

Modeling systems of infrastructure systems is necessary for optimal life-cycle management.

Haimes and Jiang (2001) extend Leontief's economic input-output models to evaluate the risk of inoperability in interconnected infrastructures as a result of one or more failures subject to risk management resource constraints. Interdependence is captured in Leontief's production coefficients, which here represent the probability of an interconnected infrastructure component propagating inoperability to another component. Infrastructure components are also subject to independent risks of failure. Finally, each component has an associated coefficient reflecting the amount of some resource (e.g., funds or personnel) required to manage the risk of inoperability. Thus, infrastructures are interdependent through failure propagation, specified in geographical, functional, temporal, and political dimensions, and through the allocation of limited resources for risk management. The authors also propose a hierarchical adaptation of this model to avoid over-aggregation and reductionism, reduce the dimensions of problems, provide more realistic systems models (both static and dynamic), and enable multi-objective analyses.

Another approach based on economics by Friesz et al. (2001) defines a spatial computable general equilibrium (SCGE) model of an economy comprised of spatially separated markets interconnected by a generalized transportation network. Each infrastructure model is conceptually extended to capture interdependencies using a multilayer network of SCGE models with interlayer coupling constraints. The authors first identify five sources of interdependency with the aim of devising a mechanism to express them mathematically. Interdependencies can be physical, budgetary, market-based or spatio-economically competitive, information-based, or environmental. The static model yields equilibrium values for the supply price of the commodity (e.g., goods, passengers, messages, data, water, or energy), flow quantity and path, levels and locations of commodity production, and transport costs. Methods of modeling the system dynamically, including ABS, are suggested for evaluating and enhancing infrastructure systems design and capital budget allocations for operations, maintenance, and replacement.

ABSs are emerging as the most promising modeling techniques for predicting, controlling, and optimizing infrastructure systems. Like CASs, agents in ABSs execute relatively simple decision rules within the structural definition and constraints of the infrastructure system(s). Agents' decisions are responses to the information they have about the system, some of which may be sensed. ABS has two advantages. First, ABS can represent CAS without resorting to inappropriate analytical models; at the same time, it can enable predictions of the desirability of different policy options. North (2000) developed a series of ABSs to explore pricing and various levels of competition with deregulated electric utilities. The simulations addressed the effects of price swings for natural gas, such as those that would follow a pipeline interruption; the number of companies needed for truly competitive markets; and the identification of companies colluding to drive up electricity prices.

Second, ABS may offer an improved control paradigm that can be implemented at the hardware level. With centralized control, infrastructure systems are vulnerable to the weakest link; distributed control can limit, localize, and allocate risk. Some models have been proposed whereby infrastructure system agents could automatically reconfigure a system to "heal" failures (Amin, 2000). Distributed control also enables distributed power generation, as well as the control of multiple infrastructure systems.

The meta-infrastructure system approaches described above are reasonably representative of the current state of the art. It is interesting to note that none of these frameworks deals explicitly with interdependencies induced by sharing input resources. Physical interdependencies in Rinaldi come the closest; Friesz et al. and Haimes and Jiang both use implicit notions of activity levels.

Interdependencies from resource sharing arise when improved efficiency is achieved by reducing redundancy across systems. When systems use resources completely independently of one another to provide their respective services, the systems are independent with respect to that resource, assuming perfect market competition. If the resources could have been shared but were not, the resources were redundant. Every reduction in redundancy in these systems through resource sharing creates a certain class of system interdependency.

Reduced redundancy, the elimination of a redundant power generator, and high utilization of remaining generators, for example, can render a system more vulnerable. A beneficial example of resource sharing would be a hydropower facility and a drinking water plant that use and reuse the same river flow to generate their respective services. In fact, the chief of the Bureau of Reclamation recently stated that to use water stored by 457 dams in the western United States as efficiently as possible water should be passed through the dams multiple times for recreation, power generation, and irrigation (WaterTech Online, 2001). Finally, tracking resource quantities explicitly would make possible more accurate assessments of the external costs (e.g., environmental impact) of using those resources.

With centralized control, infrastructure systems are vulnerable to the weakest link.

Case Study

Colorado Springs Utilities, an innovative western water utility that has been researching multiple uses of water resources, estimates the benefits would be worth more than $500,000 per year, not including windfalls from high electricity prices (Jentgen, 2001). Their energy and water quality management system (EWQMS) is conceptually an extension of electric utilities' energy management systems (EMSs), which include power generation control and real-time power systems analysis. Some aspects of the EWQMS can be substantially more complicated than EMS. For example, in an EWQMS where hydropower is an option, decisions about pumped storage are coupled with the selection of electricity sources to exploit time-of-day electricity pricing. Alternatively, if spot market prices are exorbitant, hydropower might best be used to generate electricity for sale. Whereas EMS's power generation control has a short-term load-forecasting component, the EWQMS has two sets of demands to predict and satisfy: one for electricity and one for water. In addition, scheduling decisions must also consider (1) what quantity of raw water from which source is subject to water rights and quantity and quality constraints, given variable pumping costs; (2) what quantity of water to treat at which plant, given variable treatment costs; and (3) what pumps to use for distribution, collection, and wastewater treatment and which ones to take off line for maintenance.

This case study shows how shared resources can simultaneously improve efficiency and reduce vulnerability through resource reuse. Heller et al. (1999) discuss the concept of shared resources as a means of achieving regional eco-efficiency. In this context, information system boundaries are extended to coordinate the shared production, consumption, treatment, or reuse of electricity, water, and wastewater resources among regional utilities and manufacturing facilities.

Future Research

Interdependencies in civil infrastructure systems require much more attention and study. As long as we treat infrastructure systems in isolation, we will perpetuate suboptimal systems operations, inefficient resource use, and vulnerability to the risks and uncertainties of failure.

To meet the exigencies of our greatly changed world, we must rethink and reengineer infrastructure systems.

We need new frameworks for understanding systems of infrastructure systems as a basis for modeling the complex behaviors of individual infrastructure systems as well as coupled systems. Specifically, research should be focused on meta-infrastructure systems models in the context of multiple large-scale complex adaptive systems. We also need methodologies for designing and operating these systems of systems in a way that provides the best trade-offs in terms of efficiency, vulnerability, resiliency, and other competing objectives, under normal and disrupted conditions. Another area for research is the development of multiple performance measures and economic models that accommodate them to capture multiple stakeholders' interests and decision makers' missions, constituencies, resources, and schedules. Design and operations must be performance-based. Metrics and economic models must address organizational and human errors and threats, as well as the risks and uncertainties of extreme events. New paradigms for distributed control should be investigated and compared with centralized control options. To provide more and better information, research could focus on the design and development of infrastructure-level sensor systems and data management systems. Finally, efforts must be directed toward educating and training a workforce for research in infrastructure interdependencies.

Infrastructure systems, which were engineered to facilitate the competitive flow of people, goods, energy, and information, have expanded far beyond their original design specifications. To meet the exigencies of our greatly changed world, we must rethink and reengineer infrastructure systems life cycles to serve their original purposes under new conditions, such as globalization, deregulation, telecommunications intensity, and increased customer requirements. We must make sure information system interdependencies contribute to solutions and do not exacerbate, or even become, the problem.

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Note

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Reengineering the Paralyzed Nervous System

P. Hunter Peckham

Whether the damage is congenital, traumatic, or age-related, improving neural connectivity and restoring function can greatly improve a person's quality of life.

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Damage to the central nervous system is the major cause of disability in the United States. In some cases, such as in spinal cord injuries or strokes, connectivity has been lost because the pathway has been severed. In other cases, such as in Parkinson's disease, the neural circuits behave in a disordered fashion. Whether the origin of the damage is congenital, traumatic, or age-related, improving neural connectivity and restoring function has a major impact on the lives of people with these injuries. Many approaches to restoring the connectivity of neural elements are being explored (e.g., gene therapies, stem cell transplants, tissue engineering). One of the most promising is engineering, which can provide an interface with the nervous system to restore functions.

Through the delivery of low levels of electrical current in precise ways, control of the nervous system can be regained and function restored. Understanding how such an interface works requires a fundamental appreciation of the structure of nerves and how they work. First, consider a single nerve fiber. From the cell body, or soma, at one end, hundreds of dendrites emerge, through which input is provided to the cell. Only one axon leaves the cell. The axon delivers information to another structure, such as another nerve cell or a muscle cell. Electrical stimulation is usually delivered to the axon somewhere along its length. The electrical current causes the permeability of the membrane to change causing an efflux/influx of sodium, potassium, calcium, and other ions. When the difference across the membrane reaches a sufficient level, an action potential is generated that propagates along the axon in both directions from its point of origin. This fundamental principle, called "gating" the membrane potential, is the basis for restoring function to the nervous system by electrical activation. The action potential generated by an electrical current causes events analogous to the events that occur in the normal generation of nerve impulses.

Using electrical current to restore neural function has many advantages. First, most events involving the nervous system are communicated naturally by electrical means. Second, electrical stimulation has the capacity (1) to *activate* a single nerve fiber or multiple nerve fibers to generate movement and sensation, (2) to *inhibit* the firing of nerve fibers to reduce spasticity and pain, and (3) to *activate or inhibit* complex neural circuits, called neuromodulation, to change the firing of entire circuits of cells so it could be used to restore a wide range of different functions. Third, the effect of electrical stimulation can be *localized*, and turning off the current can eliminate the effect. Currents could also be delivered in such a way as to prolong the effect by taking advantage of the inherent plasticity of the nervous system. Fourth, electrical stimulation is incredibly *efficient*. A very small amount of current can generate enough muscle activation to lift the body. Electrical stimulation also acts very rapidly; the effect can be observed in seconds. Finally, electrical stimulation *can be applied safely*. Methods of delivering electrical current to biological tissue have already been developed through careful research and testing. Safe, stimulating wave forms that use bidirectional pulses with charge densities below established limits are well tolerated by biological tissues. Thus, electrical stimulation is an extraordinarily versatile, effective, and safe tool for manipulating the activity of the nervous system.

Electrical activation of the nervous system is applicable to virtually every disorder involving the central nervous system (i.e., the brain and spinal cord). Some devices have already been granted regulatory approval and are commercially available in the United States. These include devices for restoring hand function, controlling bladder and bowel function, controlling respiration in spinal cord injuries, suppressing seizures in epilepsy, suppressing tremors in Parkinson's disease, and restoring audition for people with hearing loss. Clinical research is being done on human subjects to enable patients to stand and walk, swallow, control the anal sphincter, and see. Basic research is also continuing on all of these applications to improve function and extend their applicability. For example, electrical stimulation has had limited success in restoring function in individuals with stroke, brain injuries, multiple sclerosis, and cerebral palsy, although theoretically their neurological disabilities can be overcome. For patients with spinal cord injuries, for example, the technique must be operable for extended periods of time, perhaps for 50 years or more. In addition, these injuries affect more than one system, the limbs and bladder, for instance. Ideally, therefore, the technology will be applicable to multiple systems.

The use of a neuroprosthesis always involves trade-offs between physiological, technological, and clinical factors.

Implementation of Neuroprostheses

Several factors must be considered in the clinical implementation of neuroprostheses. The use of a neuroprosthesis always involves trade-offs between physiological, technological, and clinical factors.

Physiological Considerations

Physiological factors are associated with the creation of a safe, effective interface between the prosthesis and the nervous system. First and foremost, the delivery of the electrical stimulus must be safe. A sufficient charge must be directed across the nerve membrane to depolarize it and generate action potentials, without generating toxic species in sufficient quantities to cause damage. Destruction (necrosis) or damage to the nerve tissue would exacerbate the problem. To understand the complexity of the problem, consider a devise that could restore respiration. Biphasic (bidirectional or AC) current-regulated pulses with charge reversal have been found to be effective. Eliciting an action potential in a compound nerve may require 10–20 mA at 30 V at a frequency of 20 Hz 24 hours per day for up to 50 years.

Implantable devices are most effective for prostheses that must be used for a substantial part of a person's life.

Another physiological consideration is the control and coordination of activation of the muscle. The physiologic control of muscles is graded, and this must be duplicated in the re-engineered system. There are only two fundamental mechanisms for controlling muscle force, (1) activating more muscle fibers (recruitment) or (2) activating muscle fibers faster. The latter leads to fatigue. Therefore, the preferable rate of stimulation is 20 Hz or less. Controlling force by recruitment requires that the number of nerve fibers activated be increased as the controlling current is increased. The resulting activation is a nonlinear function, generally sigmoid shaped. High-gain regions of the relationship may cause difficulties in control because small changes in current can cause large changes in the number of activated nerve fibers, as can small movements between the electrode and the nerve. In addition, a fundamental characteristic of muscle is that its force is dependent on its length; therefore, muscle length must also be considered in artificial control. Generally, an action is not caused by the "simple" generation of force from a single muscle but is the result of many muscles working together to produce the desired movement. Even for a simple movement, this means that one muscle (an agonist) increases in strength as a second muscle (an antagonist) works in opposition and decreases in strength. When one considers a complex action, such as walking or moving an arm, one can begin to appreciate the complexity of restoring movement through electrical activation.

The stability of the electrically activated response must also be considered. Muscles become fatigued with sustained contraction, whether naturally or electrically induced. With electrical stimulation, however, muscles become fatigued faster for two reasons. First, in an electrically stimulated contraction, there is less rotation of activated fibers than in a natural, voluntary contraction. Second, paralyzed muscles are generally less able to sustain force because their metabolic properties have been compromised since the injury. Electrical activation can effectively reverse this "disuse atrophy" to increase the fatigue resistance of paralyzed muscles.

Technological Considerations

The fundamental technology in systems for neuroprosthetic devices includes stimulators, electrodes, sensors, and the lead wires or communication channels that connect them. The form of the technology depends on the application. In the examples given above, which must be used for a substantial portion of a person's life, the most effective devices would be implanted. The specificity and reliability afforded by implantation results in vastly improved function and convenience for the user. Therefore, the device must be thoroughly reliable, designed to accommodate enhancements, and be repairable without compromising the remaining components.

The requirements for an electronic device that can operate in the body for 50 years are stringent. For example, the current technology used to control the motor system consists of a multichannel, implantable stimulator with multiple leads that extend from the implanted electronics to the terminal electrodes placed adjacent to the nerve-muscle connection in the distal limb. The implantable stimulator contains hybrid microelectronics to provide the stimulation and control functions. The battery is not implanted because power consumption is too high for this to be practical. (To get an idea of power consumption, consider a device with eight channels of stimulation activated at 10–20 mA at 30 V at a frequency of 20 Hz 24 hours per day.) Currently, the electronics are powered and controlled by a radio-frequency signal transmitted through the skin with tuned coils (transmission frequency approximately 6.7 MHz).

The implanted electronics are protected from moisture by a titanium package with glass-metal feedthroughs for the leads. The configuration of the package depends on the application; generally 8 to 16 feedthrough pins are used for the stimulation and control functions. The leads present a difficult mechanical challenge because they are subject to repeated cycles of both bending and stretching. In addition, each lead must have a midline connector so repairs can be made in the event of failure. Stress concentrations are created both at these connectors and at the junction where the leads exit the feedthroughs. In addition, the passage of current through the electrodes causes electrochemical reactions at the interface to the tissue, which can cause degradation of the electrode, as well as the tissue. The biological compatibility of the materials with the surrounding tissue is essential in all types of implanted devices because any weakness in the design will be exploited by the environment. The problem is even more difficult for neuroprosthetic applications in terms of protecting the implanted electronics and ensuring the long-term continuity of the lead electrode.

Clinical Considerations

In developing a neuroprosthetic device, it is particularly important to understand the function that is to be restored and how this aspect of the disability is treated medically. The technology must be not only functional, but must also be deployable by clinical practitioners (physicians, therapists, and nurses) whose appreciation of the complexity of the technology may be limited. The design must also meet the requirements of the user, such as an acceptable level of risk, time commitment, and the effort required for implementation and training. The neuroprosthesis must not only function acceptably, but it must also be easy and natural to use and easy to put on. Acceptable function may be less than full, normal function.

Restoring Upper Limb Function

The focus of our work has been on a neuroprosthesis to restore hand and arm function (Figure 1) for people with cervical-level spinal cord injuries. These individuals have lost control of their hands and lower extremities but retain control of their upper arms. The neuroprosthesis we have developed incorporates an implantable sensor that transduces joint angle (IJAT), a multichannel stimulator-telemeter, and an external control unit. Movements of the wrist are transduced by the IJAT and used to control the stimulation applied to the paralyzed finger and thumb muscles. Two grasp patterns are provided: (1) lateral pinch-release, in which the thumb contacts the side of the index finger; and (2) palmar prehension-release, in which the index and long fingers oppose the thumb. The former grip is typically used for picking up or holding small objects and the latter for grasping larger objects. Grasp is proportional; flexion of the wrist corresponds to full hand opening, and wrist extension corresponds to maximum grasping strength. Intermediate positions of the wrist correspond to intermediate grasp positions between these two extremes.

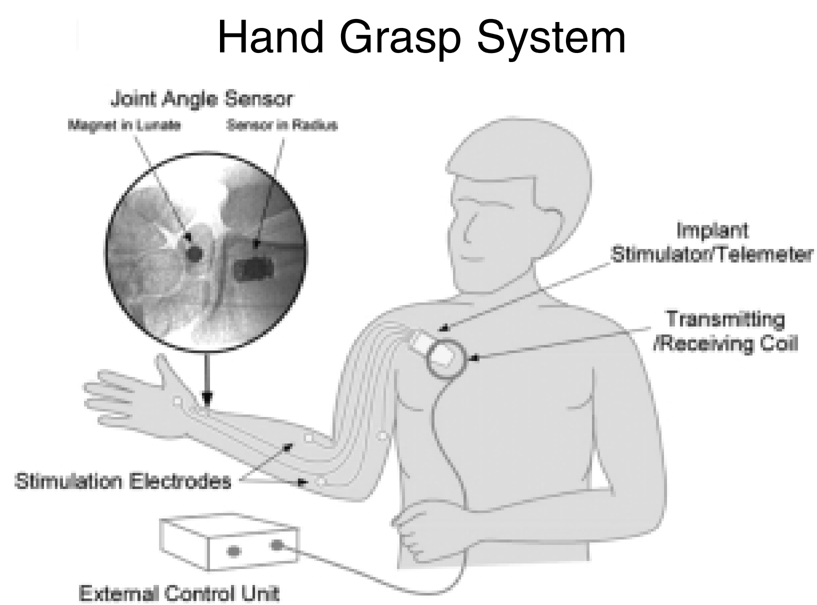

FIGURE 1 Sample implementation of neuroprosthesis for restoration of hand-arm control. Source: Bhadra et al., 2001.

The system operates in the following manner. Contacting an external switch turns the system on, which transmits the radio frequency to the implant from the external controller, thus powering the transducer. This also establishes the "zero" command position of the wrist, corresponding to full hand extension, which is achieved by stimulating each of the target muscles at the appropriate level. For example, for hand extension, the finger and thumb muscles are maximally stimulated, and the finger and thumb flexors are inactive. These values are stored in a look-up table, in which any given wrist position corresponds to stimulus levels for each muscle. From the position of wrist extension, the user maneuvers the hand around the object and extends the wrist, causing the flexor muscles to be stimulated to a higher level and the extensor stimulation to decrease. Activating the external switch again sets a hold command, which maintains the stimulus level even if the wrist position changes. Other switch commands allow the user to regain control, reset zero, reset hold, or turn the system off. This system also enables users to regain control of elbow extension, which has been lost because of paralysis of the triceps. The switch enables the user to select alternative modes in which the triceps is either on or off.

Advances in microsensors and bioMEMS are likely to yield great dividends.

This system is a second-generation neuroprosthesis, five of which have been implemented in human subjects. The first-generation neuroprosthesis, which has an external sensor on the opposite shoulder for control and eight channels of stimulation, has completed clinical trials (Peckham et al., 2001), has been approved by the Food and Drug Administration, and is commercially available (NeuroControl Corporation, Vallee View, Ohio). Approximately 200 first-generation devices have been implanted worldwide. Both systems enable people with spinal cord injuries to grasp and release common objects and thus perform many everyday activities, such as eating, writing, and grooming, These functions, which are essential for independence and self-sufficiency, often lead to dramatic changes in patients' lives.

Future Development

Many new tools, such as sensors, electrodes, stimulators, and detailed "instruction sets" of how to use them, are expected to become available in the future. By describing how these tools interact with the underlying neural tissue and modeling this performance, the instruction set allows us to predict how the tools will perform in various situations. Sensors that detect physical movement, pressure, or electrical activity may be used for control or feedback.

Advances in microsensors and bioMEMS are likely to yield great dividends. Current triaxial accelerometers and micropressure transducers are small enough and low-power enough to be implanted in the body. With advances in electrode technology, we will be able to stimulate selected fascicles of a whole nerve and create unidirectional impulses on the nerve. This will make complete and selective activation of nerves possible, as well as the inhibition of neural activity, such as the blocking of spastic activity or pain. These electrodes will also make it possible to record the natural activity of afferent nerve fibers for feedback and control. The development of a microelectrode will make possible the stimulation of spinal circuitry and cortical centers and selective recording from these regions. Complex high-density circuitry could be incorporated into the electrodes themselves, which could lead to direct access to the central nervous system and direct interfaces with the neural circuitry that controls complex coordinated functions at the spinal or cortical level. It could also enable us to extract control information from cortical neurons and, eventually, to translate the intention to move into signals that could be used to control movement. Finally, high-density stimulation and transmitting devices are under development that will enable the activation of more channels of stimulation in a smaller volume; this would greatly facilitate the development of complex visual prostheses.

New technology will provide tools for the development of more precise interfaces with the damaged nervous system leading to even more significant clinical results. We have already made progress in this direction by showing that afferent signals recorded from the nerves innervating the bladder during filling could be used to help control bladder activity. The neuroprosthesis for hand control described above, which uses both implantable sensors and stimulators, is undergoing clinical evaluation. This device could eliminate much of the external hardware and provide natural control of the hand that is easy for the user to learn. Systems that provide more than one function are not far away.

In the future, neuroprostheses may be used independently or in conjunction with other approaches, which may ultimately provide the best effect. For example, the plasticity of the nervous system is being revealed in clinical trials for body-weight supported walking and constraint-induced arm therapy. Function probably improves because residual spinal and cortical circuits have the capacity to alter their functions in an activity-dependent way. These adaptations are driven by the individual's remaining voluntary function but could also be triggered or reinforced by an electrical stimulus.

Using these tools effectively and developing new tools will require continued progress in our understanding of the pathophysiology of neural injury and how to interact with disordered control. As these technologies mature and become more available, advances can be expected to accelerate. New devices will almost certainly address a wider range of problems and benefit a growing number of individuals. Electrical stimulation is a powerful tool that will continue to be an essential aspect of new devices to mitigate the effects of disabling central nervous system conditions.

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Wireless Integrated Network Sensors (WINS): The Web Gets Physical

Gregory J. Pottie

Compact, low-cost WINS can be embedded and distributed at a small fraction of the cost of conventional wire-line sensor and actuator systems.

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Wireless integrated network sensors (WINS) provide distributed network and Internet access to sensors, controls, and processors embedded in equipment, facilities, and the environment. WINS combine sensor technology, signal processing, computation, and wireless networking capability in integrated systems. With advances in integrated circuit technology, sensors, radios, and processors can now be constructed at low cost and with low power consumption, enabling mass production of sophisticated compact systems that can link the physical world to networks (Bult et al., 1996; Dong et al., 1997; Lin et al., 1998; Asada et al., 1998). These systems can be local or global and will have many applications, including medicine, security, factory automation, environmental monitoring, and condition-based maintenance. Because of their compactness and low cost, WINS can be embedded and distributed at a small fraction of the cost of conventional wire-line sensor and actuator systems. Designers of systems with hundreds, or even thousands, of sensors will face many challenges.

Centralized methods of sensor networking make impractical demands on cable installations and network bandwidth. The burden on communication system components, networks, and human resources can be drastically reduced if raw data are processed at the source and the decisions conveyed. The same holds true for systems with relatively thin communications pipes between a source and the end network or systems with large numbers of devices. The physical world generates an unlimited quantity of data that can be observed, monitored, and controlled, but wireless telecommunications infrastructure are finite. Thus, even as mobile broadband services become available, processing of raw data at the source and careful control of communications access will be necessary.

In this paper, I present two scenarios illustrating different aspects of the design trade-offs. The first example is an autonomous network of sensors used to monitor events in the physical world for the benefit of a remote user connected via the Web. The second scenario explores how sensor information from an automobile could be used. A general architecture for both is shown in Figure 1. The figures does not show in detail how services can actually be supported by Internet-connected devices, but two clusters of nodes, connected through separate gateways to the Internet, can supply some services. The nodes are assumed to be addressable either through an Internet protocol address or an attribute (e.g., location, type, etc.). Unlike pure networking elements, the nodes contain a combination of sensors and/or actuators. In other words, they interact with the physical world. The gateway may be a sensor node similar to other nodes in the cluster, or it may be entirely different, performing, for example, extra signal processing and communications tasks and having no sensors. In the cluster in the top left portion of Figure 1, nodes are connected by a multihop network, with redundant pathways to the gateway. In the bottom cluster, nodes may be connected to the gateway through multihop wireless networks or through other means, such as a wired local area network (LAN). The nodes in different clusters may be all one type or they may vary within or among clusters. In a remote monitoring situation, part of the target region may have no infrastructure; thus, the multihop network must be capable of self-organization. Other parts of the region may already have assets in place that are accessible through a preexisting LAN. There is no requirement that these assets be either small or wired. The point is to design a system that makes use of all available devices to provide the desired service.

In the next section, I briefly describe some design heuristics. This is followed by a discussion of current research on the deployment of large networks in areas without infrastructure support. The next section focuses on how sensor networks in vehicles can be linked with the Internet.

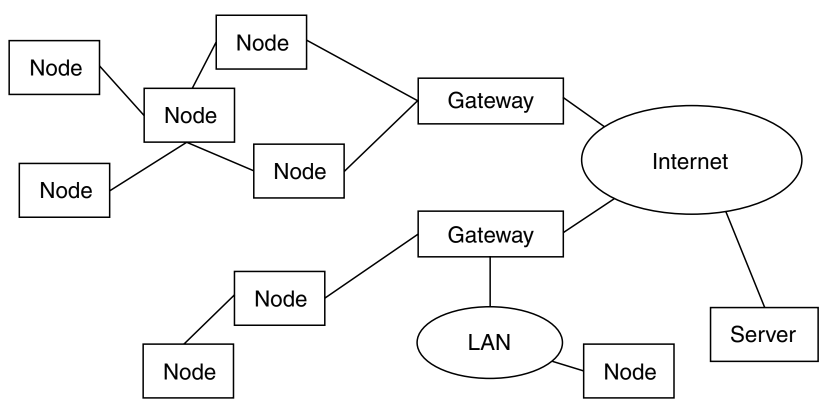

FIGURE 1 WINS network architecture.

Design Heuristics

Pottie and Kaiser (2000) described some of the fundamental physical constraints on the cost of sensing, detection, communication, and signal processing. They identified five basic design constraints:

1. For reliable detection in many situations, sensors must be in close proximity to a physical event (e.g., physical obstructions to cameras); thus large numbers of sensors may be needed. The type of information obtained with large numbers of sensors is qualitatively different from the information obtained with remote arrays.

2. The cost of sensors, radios, and signal processing will come down as the cost of integrated circuit technology comes down. The cost of batteries and other energy sources, however, will come down much more slowly.

3. The cost per bit for communications energy is often many orders of magnitude higher than for the energy required to make decisions at the source. Whereas processing cost is limited only by current technology, the efficiency of communications has fundamental limits.
4. Networks must be self-organizing to be economical.
5. Scaling to larger numbers while maintaining physical responsiveness requires a hierarchy with distributed operation at lower levels and increasingly centralized control at higher levels.

With machines, we can provide highly differentiated abilities to devices at different levels of the hierarchy.

Note that a hierarchy does not necessarily imply a need for heterogeneous devices. Consider, for example, a human organization. The processing abilities are roughly equal at all levels, but in progressing up the chain, different information is processed at different levels of abstraction and aggregation. Commands moving down the chain also differ in the level of abstraction, from policies to work directives, that require different levels of interpretation. This flexibility enables individuals at the lower levels to deal with local changes in the work situation much faster than if a central controller had to be consulted for each action; at the same time, global goals continue to be pursued. With machines, of course, we can provide highly differentiated abilities to devices at different levels of the hierarchy. For example, a backbone long-range high-speed communications pipe can greatly reduce latency compared to multihop links. Thus, even though a logical rather than physical hierarchy is arguably much more important to scalability, the designer of large-scale systems must not be seduced by the siren song of homogeneity and should consider both. In any case, homogeneity is impractical in long-lived systems composed of integrated circuit components. For systems that use the Internet, the architecture must accommodate successive generations of more powerful components.

Remote Monitoring

I will now consider a more concrete example of a system that identifies particular classes of targets passing through a remote region. The targets could be military vehicles, species of animals, pollutants, seismic events on Mars, or, on a smaller scale, enzyme levels in the bloodstream. In any case, let's assume there is no local power grid or wired communications infrastructure, but that there are long-range communications for getting information to and from a remote user. In laying out a network like the one depicted in Figure 1, both energy and communications bandwidth can be critical constraints. If the network must scale in the number of elements, much of the signal processing will have to be performed locally. For example, in studying the behavior of animals in the wild, a dense network of acoustic sensors might be used. The nodes would contain templates for identifying the species emitting the call. Nodes that made a tentative identification could then alert their immediate neighbors so the location of the animal could be roughly determined by triangulation. Infrared and seismic sensors might also be used in the initial identification and location processes. Other nodes would then be activated to take a picture of the target location so a positive identification could be made. This hierarchy of signal processing and communications would be orders of magnitude more efficient in terms of energy and bandwidth than sending images of the entire region to the gateway. In addition, with the interaction of different types of nodes, most of the monitoring would be automated; humans would be brought into the loop only for the difficult final recognition of the visual pattern of preselected images. Upon positive identification, the audio and infrared files corresponding to the image would be added to a database, which could subsequently be mined to produce better identification templates. Note that with long-range communications links (via the gateway), the user could make the full use of Web-accessible utilities. Thus the end user would not have to be present in the remote location, and databases, computing resources, and the like could all be brought to bear on interpreting the (processed) data.

Experimental apparatus for initial exploration of an application domain and the apparatus that will actually be needed for large-scale deployment may differ. Because networked sensors have hitherto been very expensive, relatively little array data are available for most identification purposes, and sensors have typically been placed much farther from potential targets than they will be with WINS. This means, paradoxically, that initially fairly powerful nodes will have to be constructed to conduct large-scale experiments to collect raw data and suitable identification algorithms developed from the resulting database. In experimenting with different networking algorithms, it is desirable, from the point of view of software development, to provide an initial platform with considerable flexibility. The DARPA SensIT Program has produced development platforms to support this kind of experimentation (Kumar, 2001). Other researchers have focused on specializing functions and miniaturizing components to demonstrate that large networks of small nodes can be produced. Sensoria Corporation's WINS NG 2.0, for example, nodes include ports for four sensors, a real-time digital signal processor, memory, a main processor running Linux, a battery and port for external power, the global positioning system (GPS), Ethernet, an RS-232 port, and two radios for convenient synthesis of multihop networks. Software interfaces have been created to enable programmers to control remotely a large number of physical attributes of nodes and to download new applications remotely. Thus, diverse users can produce algorithms for networking, target identification, and distributed database management. On another track, researchers at the University of California-Berkeley are engaged in producing very small nodes with limited sensing and communications abilities to demonstrate that sensing, signal processing, and communications can be combined in a miniature package.

Automotive Applications

All automobiles produced recently include many processors and sensors, as well as a variety of networks for sensing, control, and entertainment systems. For example, hundreds of sensor parameters are accessible through the on-board diagnostic port. However, there are no connections between these networks and external communications systems, such as cellular phones. The Automotive Multimedia Interface Collaboration (AMI-C) has been working on ways to connect these networks and provide standardized buses in automobiles so a wide range of consumer electronics can be installed. This would create an automotive intranet that could then be conveniently accessed via the Internet (AMI-C, 2001). Ports on the bus could include any of a number of radios, so wireless devices in the vehicle could become part of the intranet, or short-range high-speed communications could be possible between a vehicle and a residence or service station.

A key component of the architecture envisioned in the AMI-C standard is a gateway that separates proprietary and safety-sensitive systems in the automobile from after-market consumer electronics. The gateway would have separate ports for interfacing with legacy networks and consumer buses. The gateway would also host software for managing the various services envisioned for internet-connected vehicles. For example, maintenance information would enable manufacturers to learn how their vehicles are actually used or enable consumers to evaluate the need for repairs and determine the effectiveness of repairs by comparing data before and after. Other potential uses could include uploading of entertainment information and locating nearby retail stores, restaurants, or service stations.

Current cell phones have a much higher cost per bit than other means of communication.

A vital function of the gateway in making such services economical is management of the communications links. Presently, cell phones have a much higher cost per bit delivered than other means of communication. However, if the automobile also has a short-range broadband link, such as IEEE 802.11b, then information might be processed and stored until it can be uploaded to a home computer when the car is parked near the residence. In a similar way, entertainment information or software upgrades could be downloaded overnight. Another approach would be to communicate over high-speed links at a gas station during refueling, for example, to receive updated information or complete a purchase of digital audio files. For very high-priority services, such as emergency assistance, the cell phone would be used, rather than waiting until a high-speed port comes into range. Based on the vehicle operator's preferences, the gateway could choose an appropriate mix of local processing, storage, and communications that would provide services at the desired costs.

Providing services to millions of vehicles presents enormous challenges.

The high-level requirements for the design of the gateway are surprisingly similar to the requirements for the development nodes described in the first scenario for conducting large-scale data collection experiments. Common requirements include real-time components, general purpose processors, wired and wireless network communication interfaces, application program interfaces that permit construction of software by third parties, and remote controllability via the Web. Although the devices are quite different, the same architecture applies. For a vehicle, the gateway may have some devices that respond to the physical world directly, or such devices may be accessible through local area networks in the vehicle. For the sake of economy, some of these devices or the gateway would perform local processing. Rather than sending a continuous record of engine temperature, for example, detailed reports might be stored only when temperatures cross a critical threshold or when the temperature is high and another sensor indicates possible problems. Further processing might even make a preliminary diagnosis, after which a query to an expert system located on the Web might be made. In this way, the vehicle would not have to host the complete diagnostics system.

Remote monitoring and control would also be attractive for other reasons. Vehicle owners will probably not want to program their preferences while operating the vehicle, and any sensible regulatory regime will surely discourage driver distractions. Scaling is also a concern. Providing services to millions of vehicles presents enormous challenges, both in terms of the huge volume of data that can be generated by vehicles and the quantity of entertainment information that may have to be transported to them. With a gateway and back-end Web-server network that enables remote downloading of software, many different companies will be able to compete for providing information services to automobile owners.

Conclusion

Intertwined network processing is a central feature of systems that connect the physical and virtual worlds. Research is now proceeding on the design of small, specialized nodes that could potentially be deployed in very large numbers and on the creation of dense networks of larger nodes that can be used to learn more about the types of networking, sensing, and signal processing that will be needed in future systems. Because of constrained communications, design considerations for scalable networks will be similar even if data rates and processing capabilities vary greatly. Signal processing and communications must be considered together for a very broad range of systems that interface to the physical world.

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NAE News and Notes

NAE Newsmakers

Ted B. Belytschko, chairman of the Department of Mechanical Engineering, Northwestern University, was awarded the ASME **Timoshenko Medal** for significant contributions to finite element analysis and the development of explicit transient algorithms, one-point quadrature elements, subcycling, meshless methods, and other widely used techniques.

Bruno A. Boley, professor of civil engineering and engineering mechanics, Columbia University, was awarded the ASME **Daniel C. Drucker Medal** for outstanding academic leadership and numerous publications on elastic stability, structural dynamics, and thermal stresses. Dr. Boley is coauthor, with J.H. Weiner, of *Theory of Thermal Stresses* (Dover Publications, 1997), which has been a standard reference for more than 40 years.

Geoffrey Boothroyd, cofounder of Boothroyd Dewhurst, Inc., and professor emeritus, University of Rhode Island, was awarded the ASME/SME **M. Eugene Merchant Manufacturing Medal**. Dr. Boothroyd was recognized for the development and ongoing refinement of design for manufacture and assembly (DFMA), a powerful, breakthrough methodology that has enabled manufacturers worldwide to improve the quality of their products and reduce costs.

Howard Brenner, W.H. Dow Professor of Chemical Engineering, Massachusetts Institute of Technology, received the 2001 **Fluid Dynamics Prize** of the Division of Fluid Dynamics of the American Physical Society. He was cited for "outstanding and sustained research in physico-chemical hydrodynamics, the quality of his monographs and textbooks, and his long-standing service to the fluid mechanics community."

The American Institute of Hydrology presented the **Ray K. Linsley Award** to **John J. (Jack) Cassidy** at its annual meeting in Minneapolis on October 15, 2001. The award was established in 1988 to honor **Ray K. Linsley**, a consultant and long-time professor of hydrology at Stanford University and a founder of the American Institute of Hydrology. Cassidy, the fourteenth recipient, was honored for his "major contributions to engineering hydrology."

Ernest L. Daman, chairman emeritus, Foster Wheeler Development Corporation, was honored by **ASME International** for technological innovations (including the fluidized-bed boiler), distinguished service in the White House Office of Science and Technology, and excellent leadership of ASME.

Elias P. Gyftopoulos, professor emeritus of mechanical engineering and nuclear engineering, Massachusetts Institute of Technology, received the ASME **Edward F. Obert Award**. He was recognized for two outstanding papers, "Entropy. Part I: Statistics and Its Misleading Disorder" and "Entropy. Part II: Thermodynamics and Perfect Order" (published together as "Entropies of statistical mechanics and disorder vs. the entropy of thermodynamics and disorder," *Transactions of the American Society of Mechanical Engineers* 123:110–118).

John W. Hutchinson, professor of applied mechanics, Harvard University, was awarded the ASME **Robert Henry Thurston Lecture Award** for seminal contributions to the understanding of the nonlinear behavior and failure of materials and structures. Dr. Hutchinson is the author of more than 190 publications.

Wolfgang G. Knauss, professor of aeronautics and applied mechanics, California Institute of Technology, received the ASME **Warner T. Koiter Medal**. Dr. Knauss was recognized for seminal contributions, including experimental and analytical models, to the understanding of time-dependent behavior in polymeric materials and structures.

Herbert Kroemer, professor of electrical engineering and materials, University of California, Santa Barbara, was recently honored when asteroid number 24751 was named after him. The asteroid was discovered in 1992 by German astronomer Freimer Boerngen. The Minor Planet Center of the International Astronomical Union in Cambridge, Massachusetts, has approved the name. In 2000, Dr. Kroemer shared the Nobel Prize in physics with Zhores I. Alferov for the development of semiconductor heterostructures used in high-speed electronics and optoelectronics.

Henry McDonald, director, NASA Ames Research Center, was honored by **ASME International** for significant contributions to the development of computational fluid dynamics analyses for aerodynamic vehicles and leadership in NASA's information technology, astrobiology, and nanotechnology programs.

William D. Nix, Lee Otterson Professor of Engineering, and professor, Department of Materials Science and Engineering, Stanford University, received the ASME **Nadai Medal**. Dr. Nix was recognized for his research on the relationship between microstructures or nanostructures and the mechanical properties of thin films and bulk structures. He is the author of more than 300 scientific papers.

George P. Peterson, consultant, was awarded the ASME **Heat Transfer Memorial Award** for outstanding contributions in the area of phase-change heat transfer and pioneering investigations of microscale heat pipes. His contributions in these fields have earned him international recognition.

Warren M. Rohsenow, professor emeritus, Massachusetts Institute of Technology, received the **ASME Medal** for seminal and enduring contributions to the science and engineering underpinnings of the thermal power industry. Dr. Robinson pursued pioneering research on gas turbines, nuclear reactors, and cooling towers.

Robert C. Stempel, chairman, Energy Conversion Devices, Inc., was awarded the ASME **Soichiro Honda Medal** for technical and business leadership in the automobile industry and for his contributions to the development of the catalytic converter, the high-energy-storage nickel metal hydride battery, and other vehicle technologies that provide both environmental safety and high performance levels.

Alan M. Voorhees, chairman of the board, Summit Enterprises, Inc., was recently inducted into the **Rensselaer Alumni Hall of Fame**. Voorhees was a pioneer in urban planning and traffic forecasting. He is a former Rensselaer trustee and principal supporter of Rensselaer's Voorhees Computing Center.

Sheila E. Widnall, Institute Professor, Massachusetts Institute of Technology, received the ASME **Spirit of St. Louis Medal** for exemplary leadership in the field of aerospace sciences and for significant contributions to fluid mechanics, particularly the understanding of how vortex structures contribute to noise in rotary wing vehicles and how their decay can be accelerated.

Six NAE members were recently selected as 2001 **Eta Kappa Nu eminent members**: **Norman R. Augustine, Charles Concordia, Edward E. David, Jr., Roland W. Schmitt, Mischa Schwartz,** and **John Brooks Slaughter**. Eta Kappa Nu, the Electrical and Computer Engineering Honor Society, established the rank of eminent member in 1950 "as the society's highest membership classification, to be conferred on those select few whose technical attainments and contributions to society through leadership in the field of electrical and computer engineering have resulted in significant benefits to humankind." Ninety-three eminent members have been honored since the first award in 1950.

2001 Annual Meeting

NAE Class of 2001.

Nearly 700 members, foreign associates, and guests participated in this year's annual meeting, which began on Saturday, October 6, with the orientation of the Class of 2001. That evening, the NAE Council honored the 74 newly inducted members and eight foreign associates at a formal dinner in the Great Hall of the National Academies building.

The public session on Sunday, October 7, was opened by **George M.C. Fisher**, chairman, Eastman Kodak Company. Dr. Fisher's talk, "Technology, Leadership, and Public Policy," focused on the role of engineers in the complex world following the terrorist attacks on September 11. Future engineers, he said, must have a place at the policy table, must understand the human dimensions of technology, must be able to communicate effectively and be aware of cultural diversity, and must be familiar with complex global issues (see p. 32 for the text of Dr. Fisher's remarks). **President Wm. A. Wulf** then addressed the group on engineering issues related to the tragedies of September 11. He described the newly established Academy-wide task force on terrorism and encouraged all NAE members to offer help wherever and whenever possible (see p. 35 for the text of Dr. Wulf's remarks). The induction of the Class of 2001 followed President Wulf's address.

After a short break, the program resumed with the presentation of the 2001 Founders Award to **Chang-Lin Tien** and the Arthur M. Bueche Award to **Ian M. Ross**. Dr. Tien, who served as the seventh chancellor of the University of California, Berkeley, from 1990 to 1997, was the first Asian American to head a major research university in the United States. He was recognized "for his pioneering research in gas thermal radiation, thermal insulation, and microscale heat transfer, as well as for his leadership in education for

George M.C. Fisher; Norman Tien; William B. Russel, chair of the NAE 2001 Awards Committee; Ian M. Ross; and Wm. A. Wulf.

youth around the world." Because Dr. Tien was unable to attend the presentation ceremony, his son, Dr. Norman Tien, accepted the award on his behalf.

During Ian M. Ross' 30-year career with Bell Laboratories, he worked in both engineering and management capacities on many technologies, including supporting technologies for the Apollo manned space flight program. He received the Bueche Award "for his contributions to semiconductor development, his leadership of engineering for communications networks and the Apollo program, and his role in shaping national policies affecting the semiconductor industry" (see p. 39 for the text of Dr. Ross' remarks.)

In other news, Dr. Wulf announced that the 2002 recipients of the Charles Stark Draper Prize and the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education would be named in February 2002. Nominations for the Charles Stark Draper Prize, the Fritz J. and Dolores H. Russ Prize, the Founders Award, and the Arthur M. Bueche Award will be accepted from January 2 to April 8, 2002.

A new feature of the program was the first Lillian M. Gilbreth Lecture by Young Engineers, named in honor of Dr. Gilbreth, the first woman inducted into the NAE. The Gilbreth Lecture was established in 2001 as a means of recognizing outstanding young engineers and bringing their work to the attention of the NAE membership. The first lecture was delivered by **Dr. Eric Green**, chief of the Genome Technology Branch and director of the National Institutes of Health Intramural Sequencing Center. The presentation focused on the mapping and sequencing of mammalian genomes and the isolation and characterization of genes that cause genetic diseases. (The text is reprinted in *2000 Frontiers of Engineering* and online at: <*http://www.nap.edu/catalog/10063.html*>) Dr. Green received a $1,000 honorarium and a hand-scribed certificate.

Eric Green

After the Gilbreth Lecture, President Wulf introduced Sir David Davies, president of the Royal Academy of Engineering, who addressed the meeting on the subject of international cooperation among academies of engineering to address issues of global importance. His talk was followed by a lighthearted musical interlude, "Scientific Sonnets and Other Fine Songs," by NAE member Bert Westwood and his wife Jeannie. The day's activities concluded with a reception in honor of Dr. Ross and Dr. Tien.

Sir David Davies

On Monday, October 8, a number of briefings were held on topics of interest to members: climate change science; how people learn; building a workforce for the information economy; the coming of age of the Internet; communicating with the press; grand challenges in environmental sciences; the disposition of high-level waste and spent nuclear fuel; estate planning; alternative technologies to replace antipersonnel landmines; human rights; women in science and engineering; and diversity in the engineering workforce.

The spouse/guest program offered three tours highlighting Smithsonian museums and exhibits: Think Tank and Panda exhibits at the National Zoo; the Hall of Geology, Gems, and Minerals at the National Museum of Natural History; and the "BRAIN" exhibit at the Arts and Industries Building. A fourth tour was organized to visit the Hillwood Museum and Gardens, one of the area's premiere estate museums. The museum houses a comprehensive collection of fine and decorative arts from imperial Russia and an extensive collection of eighteenth-century French art.

While spouses and guests enjoyed these private tours, members and foreign associates participated in the NAE section meetings on topics of critical importance to various engineering disciplines: aerospace engineering, chaired by **Richard H. Truly**, National Renewable Energy Laboratory; bioengineering, chaired by **Stephen W. Drew**, consultant; chemical engineering, chaired by **John L. Anderson**, Carnegie Mellon University; civil engineering, chaired by **James L. Lammie**, Parsons Brinckerhoff, Inc.; computer science and engineering, chaired by **John E. Hopcroft**, Cornell University; electric power/energy systems, chaired by **Lawrence T. Papay**, Science Applications International Corporation; electronics engineering, chaired by **Robert W. Lucky**, Telecordia Technologies, Inc.; industrial, manufacturing, and operational systems, chaired by **John G. Bollinger**, University of Wisconsin-Madison; materials engineering, chaired by **Kathleen C. Taylor**, General Motors Corporation; mechanical engineering, chaired by **Ward O. Winer**, Georgia Institute of Technology; petroleum, mining, and geological engineering, chaired by **W. John Lee**, Texas A&M University; and special fields and interdisciplinary engineering, chaired by **Charles P. Spoelhof**, Eastman Kodak Company.

A highlight of the meeting this year, as always, was the annual reception and dinner dance, held Monday evening at the J.W. Marriott Hotel. Entertainment was provided by *The Capitol Steps*, a troupe of congressional staffers turned comedians who travel the country satirizing the very people who once employed them. Music and dancing followed the performance.

On Tuesday, October 9, the NAE presented this year's technical symposium, "Power Plays: Shaping America's Energy Future." The subject has been given high visibility recently by questions about the price and availability of electricity in the western United States, tensions over access to domestic energy resources, and high gasoline prices earlier this year. The symposium covered the global and political contexts of the U.S. energy future, technologies to meet expanding energy needs, the effects of deregulation and restructuring, and the need to protect the environment. Hosted by President Wulf, the symposium included presentations by members **Richard H. Truly**, National Renewable Energy Laboratory; and **E. Linn Draper, Jr.**, American Electric Power Company; as well as by Andrew Lundquist, National Energy Policy Development Group; James R. Schlesinger, Lehman Brothers; Senator Jeff Bingaman (D.-N.M.), Senator Pete V. Domenici (R.-N.M.); James L. Sweeney, Stanford University; Rita A. Bajura, National Energy Technology Laboratory; and Philip R. Sharp, Harvard University.

The next annual meeting is scheduled for October 6–8, 2002.

Renaissance Engineers of the Future

George M.C. Fisher is retired chairman and CEO of Eastman Kodak Company and chairman of the NAE. He delivered these remarks October 7 at the 2001 NAE Annual Meeting.

On September 18, seven days after the New York, Pennsylvania, and Washington tragedies, a major *New York Times* story led with a professional engineer "holding court among conference tables stacked with blueprints." Normally, that would not be cause for much notice. But this engineer was trying to figure out how to keep the supporting walls beneath the World Trade Center from collapsing—a crucial question since, as he explained, "You've got the Hudson River across the street." As the story went on to detail his efforts to solve this huge, complex, and dangerous problem, I realized how rarely ordinary people ever get to read about, much less try to understand, what engineers do.

I was even more drawn to a second story on the same page in which a number of engineers were asked how skyscrapers could be defended against terrorism. How tall should buildings be? What should they be made of? How could they be built to slow down fires and protect stairwells? Would the costs be prohibitive? One can't help but notice that these aren't simply engineering issues—they're also important public policy issues. Therefore, they can't be answered by MBAs alone or lawyers or history majors. They can only be answered by or with the help of engineers who also know a lot about public policy—and who have a place at the table with the other people making the decisions. In the twenty-first century, many of the most vexing public policy questions will fit into this category. The role of engineers will have to expand dramatically as our world becomes more complex.

We all know the popular image of engineers. We're shy, retiring dweebs who wear pocket protectors, have trouble with words, and would rather be home alone with our computers, ham radios, or erector sets. And, I suppose there are just enough of us who fit that image to make us a bit defensive. The new engineers, however, the ones who will have a place at the policy table, will have to understand more than ever the human dimensions of technology. They'll have to know how to communicate effectively. They'll have to be aware of cultural diversity and complex global issues, such as globalization as it evolves from a '90s catch-phrase to a permanent reality. Globalization has two faces. A happy face—the glories of global trade and the Internet, which have eradicated boundaries, opened new paths, speeded up communication, and created enormous wealth. And a sad face—the dispossessed on the move, homeless, landless, jobless, unskilled, migrating to megacities, their cultures undermined.

Most of us in the West do, in fact, have a global blind spot. We speak of the Third World as if it were another planet, far from our own. We don't acknowledge, and perhaps we are ignorant, of the scale of the misery. Or, until last month, that that misery affects us directly. Instead, we have often had parochial tunnel vision. For politicians, that meant getting elected and re-elected. For corporate leaders, it often meant sacrificing the future for short-term results. For techies, it meant inventing new gizmos with little thought for real human needs and real human users.

The late academy member **Michael Dertouzos**, who directed the Laboratory for Computer Science at MIT, wrote of sitting on an airplane for three hours trying to design a smart card for his new laptop to work. He couldn't do it. One of his traveling companions, a pioneer in developing the Internet (no, not Al Gore) couldn't do it either. Nor could another faculty member. After a long struggle Dertouzos finally got it to work, but he had no idea how.

This seems beyond even tunnel vision: Dertouzos attributed it to an "endemic engineering mind set" so passive-aggressive toward customers that it might be named "virtual hostility." And the problem is compounded in the Third World, that place in our blind spot, which is desperate for practical solutions from a human perspective. Technology is driving several important issues that cry out for trenchant advice from engineers who understand public policy issues. Global terrorism, which **Bill Wulf** will speak about, is one such issue.

Another is Earth systems engineering. The Earth is a geological and biological habitat, but it is fast becoming an engineering artifact. We have built and built from L.A. to Tokyo with little regard for the secondary and tertiary consequences. We've drained our wetlands, paved our parking lots, spewed carbon into the air, and flushed chemicals into the water.

Now we're in a bind. We will probably never reduce carbon emissions to 1900 levels. It's much too late to conserve our way out of the problem. Sun, wind, and water probably won't be able to generate more than 10 percent of our energy needs for a long time, if ever. That leaves fossil fuels and nuclear power—and some very heavy political baggage. Hardly anyone wants to think—or is trained to think—on such a scale. But, Earth systems engineers are, and they must be at the public policy table.

Another crucial issue, as Bill Wulf mentioned to the new members yesterday, involves megacities. By 2050, there are likely to be four billion people living in cities of 10 million or more. That's the equivalent of adding eight megacities to the planet each year. At least one-quarter of their inhabitants—one billion people—will live in absolute poverty. Economic growth unfortunately will probably come at the cost of polluting the water and air. The issues of transportation, drinking water, sewage, and disease will be hideously complex. In the past we've largely ignored these issues. The public policy questions are staggering. But, if anyone can help untangle this knot of technology and human needs, engineers can.

Dire scenarios like these are at one end of the spectrum, but, at the other end, there is reason for optimism—the potential for creative solutions through new technology. An example is high-speed computation, which has already, for example, been a significant enabler of the Human Genome Project. High-speed computation will almost surely lead to advances in other fields so innovative that they are impossible to foresee. The potential applications for food production alone offer great hope to the world.

But, it is not enough for engineers to help develop these technologies. Technology by itself cannot solve problems of public policy. That is why the participation of engineers in the wider world will be vital. Who better to sit on local committees about land use? Who better to write op-ed pieces for the local newspaper? Who better to speak up and take the wind out of the sails of politicians and pundits who build their careers on simple-minded approaches to complex problems? Who better to serve in Congress, the Cabinet, the White House? Why not?

Engineering is a difficult, demanding discipline. We learn to build things, to make things work. That knowledge carries a responsibility, especially in times like these. We are NEEDED. Rhetoric cannot build a bridge, put in a sewer system, design a computer, clean the air, or design a megacity. Engineers are needed now, more than ever, to help make the world more livable—not just because it's the right thing to do, but, as we have recently learned, because angry, dispossessed people can become willing supporters of terrorist demagogues who can extract a high price from us through their murderous acts. Policy analysts sometimes refer to this as "draining the swamp"—removing the breeding ground for terrorism by improving the quality of life for all. Today the news is full of Osama bin Laden, the Taliban, and Afghanistan. It makes for unsettling, but also very sad, reading. Certainly, we must be uncompromising in our efforts to stop terrorists wherever they may be. As we do this, it is instructive to look back to when the Soviets invaded Afghanistan in 1979 and reduced its cities to rubble. The West, covertly and not so covertly, armed and trained anti-Soviet resistance groups, including the Taliban. But, when Soviet troops finally left Afghanistan after 10 years of frustration, so did the West. What if, instead, we had sent our engineers, our doctors, our agricultural experts, our business people to rebuild Afghanistan? What if our policy toward Afghanistan had been to launch a cooperative effort, hammered out by people who understood all of the consequences, technological as well as political?

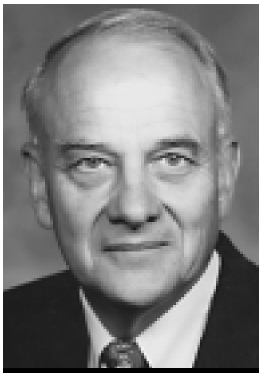
None of this happened, of course. It wasn't in anyone's parochial interest. It wouldn't have been easy to do, and it would have cost a lot of money—but perhaps a tiny fraction of what it will cost to rebuild New York. We can't know if anything would have prevented those treacherous terrorist actions, but we might have weakened their support in Afghanistan.

After September 11, parochial attitudes suddenly look petty and foolish. Old political antagonists put their arms around each other and sing "God Bless America." The show of unity and cooperation seems genuine, not forced. It's as if a sudden alignment of interests had taken place: the public interest, the national interest, and the global interest. Some of this, of course, is because people are deeply shocked and fearful. But, it's also what can happen when we understand, not just in our heads, but also in our hearts, that we are all really in this together. It's time for each of us, as engineers, to rise to the challenge.

In conclusion I would remind us that with recognition comes responsibility. As NAE members, you are the most accomplished and most respected members of the engineering profession. It's up to you.

- Widen your horizons. Be a Renaissance engineer—that is, an engineer for the twenty-first century.
- Get involved in public policy. Don't be afraid to run for office. Stand for practical, cooperative solutions. Bring your expertise to the table, and make others want to listen to you.
- Most important, go out and change the world. Make it a better place. Improve the quality of life for all the people of the Earth. Isn't that what engineering is really all about?

President's Remarks


Wm. A. Wulf

Wm. A. Wulf, president of the National Academy of Engineering, delivered these remarks October 7 at the 2001 NAE Annual Meeting.

First, I want to convey my congratulations to the new members. My own induction was not that long ago, and I have vivid memories of what it is like to become a new member. Remember that the Academy is honored, renewed, and enriched by each new class. So my welcome is heartfelt.

Originally, my talk was going to be about the public understanding of engineering and technological literacy. The events of the 11th of September changed that. I want to share with you what the Academy is doing and to solicit your ideas about what the Academy should do. But as I rewrote my remarks, I realized that this is a celebration and that there are young children in the audience. Therefore, I am going to keep my remarks as short and as light as possible—in fact, I will spend some time talking about my original subject of public understanding. Ironically, it really does relate to our present crisis.

It has been said that success has many parents. For example, many explanations have been given for how we won the Cold War. Most of them focus on the deterrence of a nuclear war—but a critical aspect of our victory was deterrence of a conventional, non-nuclear war. The reason there was no conventional war was that the NATO allies represented a credible conventional deterrent in spite of the significant numerical advantage of the Warsaw Pact in both troops and armaments. The reason we were a credible deterrent was something called the "offset strategy." We offset their numerical advantage with our superior technology, which could locate, identify, target, and remove the enemy with far greater lethality than that of our opponents. Mutually assured destruction (MAD) may have been the principle reason we never got into a nuclear war, but the offset strategy was the reason we never got into a conventional war.

We're now faced with a very, very different adversary fighting a very different kind of war. But I think the same principle applies. We cannot, we *will not* fight the way the terrorists do. So we must offset their advantage with technology.

There are ways, for example, of taking control of an airplane so that it cannot be flown by anybody on board and landing it safely. Installing such technology would eliminate the incentive for hijacking an airplane. Technology can improve our intelligence gathering and analysis by fusing information from disparate electronic databases. Technology can help us track the flow of money essential for terrorists. Technology can also help us identify the perpetrators of terrorist attacks.

Technology can also reduce the cost of security—and I don't mean just the financial cost. The conventional wisdom is that security has costs, an adverse effect on our quality of life and a reduction of our civil liberties, particularly our privacy. For example, having to stand in line for hours at airports will surely change the way we fly—change the way we conduct our lives. But the technologies I am most interested in are those that would increase our security but would not affect our life styles or reduce our civil liberties. For example, a metal detector is both less intrusive and more effective than a pat-down search.

The Academies have a long history of helping our nation in times of crisis. As you know, we were created during the Civil War. In fact, one of the first studies done by the Academy was to determine how magnetic compasses could be used aboard ironclad warships. Just prior to WWI, the National Research Council was created to handle the increased number of studies being requested by the government. During WWII, we again stepped up to the plate, and we're ready to do that again! As a trusted advisor to the federal government, the Academies can play an important role today in identifying and validating the kinds of technologies we need to combat terrorism and terrorists.

Since September 11, we have mostly been getting ready to do things. But let me enumerate some of the concrete things we have already done. One of the first things we did was write a letter to President Bush, Governor Ridge, and senior congressional leaders. Our message was "We'll do anything you want us to do. Just ask." But, we're not simply waiting to be asked. We are also taking steps on our own. On Wednesday, September 26, we convened a group of senior engineers, scientists, and current and former government officials. We invited 35 people just six days before the meeting, thinking we'd be lucky if 10 or12 showed up. As a measure of people's willingness to set aside their normal lives, and to our delight, 30 of the 35 came and spent most of the day with us.

As a result of that meeting, we put together a long list of ideas, which we are now prioritizing. We cannot do everything, but we are already implementing some of them. First, we decided that money should not be an impediment. As many of you know, we are a soft-money organization. Each time the government asks us a question, we negotiate a separate contract to answer just that question. Usually, we operate with about 30 days cash flow. But this is not the time to worry about getting paid. We decided to start working now and worry about getting paid later, if at all.

Many of our past studies are relevant to the new situation, for example, a study just two years ago on how to make buildings blast-proof. We have packaged all of these reports and posted them on the Web at *www.nae.edu*, under "Site Highlights."

In June of this year, we held a joint meeting with the Russian Academy in Moscow on the question of high-impact terrorism. The meeting was cochaired by NAE member Sig Hecker. We will convene a second meeting here in Washington by the end of the year.

About a year ago, a group of us spent a week in Iran. The United States has no diplomatic relations with Iran; indeed, Iran is listed as one of seven state sponsors of terrorism. And yet we learned that the *people* of Iran have no ill will toward Americans; indeed, quite the contrary. We were welcomed profusely everywhere we went. The Iranian people admire us, respect us, and want to work with us, and we've developed a series of seven bilateral activities with the Iranian Academy. These kinds of person-to-person contacts are very important, especially when we don't have government-to-government relations. I'd like to think they are part of the reason for Iran's cooperation since September 11.

More than 40 government agencies are responsible for some aspect of homeland defense, and an interagency task force is responsible for coordinating their antiterrorism activities. The task force came to us with a list of technologies they wished they had and asked us if any of them exists, who the leading researchers are, and if any of them could be moved quickly from the laboratory into use. In response, we are putting together committees to begin answering these questions.

We have also appointed a committee to develop a taxonomy and prioritize the threats. Believe it or not, we cannot find a usable list of the kinds of threats we face coupled with an assessment of their likelihood or the level of damage they could inflict. A lot of attention is being paid right now to airport security, but, in point of fact, that may not be where the greatest danger lies.

I am a computer engineer, and I have done research on computer security off and on over the years. On October 10, I will testify before the House Science Committee about cyber terrorism. (Dr. Wulf's testimony is available online at: <*www.nae.edu*>).

Each board in the National Research Council has been asked to devote a portion of its next meeting to thinking about how its expertise could further the cause. I have also asked the section chairs to devote a portion of the NAE section meetings tomorrow to discussing which technologies we can use to offset this threat. I am immensely proud of the willingness of our members to work on this subject—even to take substantial amounts of time off from their regular jobs so we can act quickly and effectively. I feel confident that we will offset this threat in the same way that we offset the threat during the Cold War.

The Concept of Tolerance

As I was preparing these remarks, I was reminded of a marvelous PBS television series in the 1970s called *The Ascent of Man*. It was hosted by J. Bronowski from the University of Pittsburgh. In one episode, he talked about the notion of tolerance, an incredibly important concept in engineering. Because we can't make parts perfectly, every engineering design specifies tolerances: How much bigger or smaller can something be and still work? How much heavier can it be? How much extra current can it carry? What's the range of heat it must be able to dissipate?

The systems we engineer could not work if they did not allow for some ambiguity, some uncertainty, some level of tolerance. Bronowski pointed out that science, too, in a very fundamental way, depends on the notion of tolerance. It's usually called the Heisenberg Uncertainty Principle, but Bronowski suggested that the name was misleading. The Heisenberg Uncertainty Principle states that we cannot know, for example, the position and momentum of an electron except within certain tolerances. So, Bronowski argued, it really should be called a principle of tolerance rather than a principle of uncertainty. We aren't uncertain. We are quite certain, in fact, that we can only know to within a certain tolerance.

Bronowski went on to point out that the principle of tolerance applies to human affairs as well. We cannot know everything. We must tolerate some ambiguity, some imprecision, some differences for our human systems to work. Bronowski used the horror of the Holocaust to underscore the consequences of intolerance, the consequences of people who were absolutely convinced of their rightness and could not tolerate differences and uncertainties.

As I mentioned, a group of us went to Iran last year to visit the Iranian Academy, and I want to emphasize again that our enemy is not the Iranian people. It is not Arabic people, it is not Islamic people. In our fear and justifiable anger over the events of September 11, let us not slip into intolerance of our Arabic or Islamic neighbors in this country, or of people who happen to live in countries whose leaders practice intolerance. President Bush has said that this is not a war against Arabs or Islam, and he is absolutely right. It is a war against intolerance. Let us not become victims by letting ourselves become intolerant.

Public Understanding of Engineering and Technological Literacy

Now let me turn briefly, very briefly, to my original topic of public understanding of engineering. Public understanding and technological literacy are separate programs at the Academy, but I am going to talk about them together. Why does the public need to understand engineering? Why is that important? Why do they need to be technologically literate?

Some people misunderstand what public understanding of engineering means. At least one person I talked to thought it meant that everybody ought to have a B.S. degree-level of understanding. That is clearly not what I mean. Others have adopted a Rodney Dangerfield attitude: "We don't get no respect." They would like public understanding of engineering to mean more gratitude for the contributions of engineers to people's lives—but I don't mean that either. What I mean is that, in order to function in modern society, the public needs a sufficient level of understanding of the contributions of engineering that have shaped our present society and of what engineers can (or can't) do to solve problems—to shape our future society.

Let me start with the contributions of engineers to our current society. Indulge me for a moment. Imagine that this is 1900, just 101 years ago. In 1900, very few people had electricity or telephones or automobiles, and none of those technologies had a significant impact on our social or economic lives. Without the airplane, intercontinental and transcontinental travel were too time consuming and too costly for all but the privileged few. The average life span was 46. Today, it is 76. It has increased largely because of clean water and improved sanitation. In 1900, we had no radio or television to entertain us, or more importantly, to bind us together culturally. Half of the U.S. population lived on farms, and it took that many to feed the other half. Today 2 percent of Americans live on farms. Because of agricultural mechanization, that 2 percent can not only feed the other 98 percent, but can also feed a good deal of the rest of the world. In 1900, 14 percent of households had bathtubs, and there was a total of 144 miles of paved roads in the entire country.

Okay, now come back. It's 2001. Indulge me a bit more. Do a mental comparison of how your life differs from the lives of your great-grandparents in 1900. To me, it is apparent that engineers have had a *profound* effect on the quality of life in America and, indeed, in the entire industrialized world. But do Americans know that? No. Let me tell you about an unscientific experiment that was reported in *The Bridge* five or six years ago. The experiment was done by Jonathan Cole, provost of Columbia University.

Cole went to his colleagues on the Columbia faculty and asked them to identify the most used and most important textbooks in modern American history, especially the history of the last century. He also asked the faculty of the education school to name the most important textbooks on modern history used in high schools. Then he went through those books looking for references to engineering, technology, and science. Guess what? There were hardly any. He found three pages out of 300 in some books, but most of the references were to negative effects—the atom bomb, DDT, that sort of thing. Does the average person know how dramatically his or her life has been changed since 1900 because of engineering? The answer is a resounding no! My point is not that they ought to know so they can express their gratitude to engineers. The point is that we are going to have the same kind of dramatic impact on society over the next hundred years. Therefore, any sensible public discourse about choices in the future must take into account the changes brought on by technology.

I could cite dozens of examples, but I selected the understanding of risk—the lack of a sensible discussion of risk in connection with the events following September 11. A well-known science fiction writer once observed that any sufficiently advanced technology looks like magic. I would suggest to you that the vast majority of Americans believes that the technology they use is magic. Think about it. You are speeding down I-95 south of Washington. You utter a seven- or ten-digit incantation, and all of sudden you are talking to your sister who is creeping down I-405 outside of Los Angeles. Magic! Wave a wand, push a button, and your living room is filled with live images of events halfway around the world. Magic! In a magical world there are no risks. If there is a failure, it must be somebody's fault. In fact, it must be somebody *else's* fault. It must be. With magic nothing has to go wrong.

As engineers we know a great deal about risk, and we know that a world without risk is nonsense. The problem is that a liberally educated person today does not know this. Therefore, most liberally educated people are uninformed and unable to participate in sensible discussions of many public policy issues. We need to broaden the definition of liberal education to include a healthy dose of technological literacy.

Let me give you another example. A friend of mine recommended a book called *Preparing for the 21st Century,* written by a Yale professor, Paul Kennedy, a highly respected historian. In the introduction, he explains why he wrote the book. In the 1980s he had written a very popular and influential book called *The Rise and Fall of the Great Powers*—a fairly traditional historical treatment that strongly emphasized the role of nation states. One day he was having a discussion—he actually calls it a debate—with a group of economists from RAND, and one of them asked why he had not addressed the *really* important problems—the things that were going to shape history, like the population explosion, technology, and environmental issues. The new book, *Preparing for the 21st Century,* is his response to that criticism.

I was enthused about reading the book until I was about a quarter of the way through it, when I suddenly realized that for Kennedy, technology was a completely static thing. He is a bright guy. He clearly has read a tremendous amount. I think he understands the state of technology, but he has no sense whatsoever of its dynamics—how it interacts with society, its feedback loops, its couplings, its change, its evolution in response to human needs.

Perhaps most important, he doesn't comprehend that a large number of incremental evolutionary changes ultimately add up to a revolutionary change. We are living in a world that is revolutionarily different from the world of 1900 mostly because of an accumulation of incremental, evolutionary changes. Once I realized the size of Kennedy's blind spot, reading the rest of the book was painful.

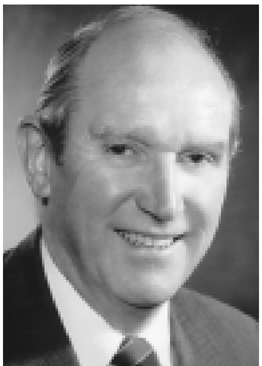
If you recall, a friend had recommended that book to me. This friend had just gone to work for the Central Intelligence Agency, specifically for the part of the CIA responsible for developing scenarios of the future that are used to think through potential threats. She is a scientist, but almost everybody else who works there is either an economist or a historian. I read some of what they have produced, and guess what? A lot of it is based on exactly the same premise—that technology is static. Technology seems to be outside of society rather than an integral part of it. We can't expect economists and historians to be experts on technology, but we can expect them to be informed enough to ask people who *are.* But they are so technologically illiterate that that question has not even occurred to them. That's scary!

So, what can or should the NAE do to improve public understanding and technological literacy? First, we must recognize that it is *our* problem. Others may be the ones who are illiterate, but we can't expect Paul Kennedy or Joe Sixpack to come to us and say, "I'm illiterate, please help me." We, the engineering profession, must take the lead. I don't have time today to talk about the programs we have initiated, but I'll describe them in future newsletters to you.

In closing, let me come back and repeat what I said at the very beginning. Welcome and congratulations to you and the new class. You renew us. You expand our expertise. You are the ones who enable us to take on important national issues. The United States is well served by having access to the expertise the Academies can marshal, to *your* expertise.

Thank you very much.

2001 Arthur M. Bueche Award



Dr. Ian M. Ross

First I wish to thank the NAE for bestowing on me the honor of this year's Arthur M. Bueche Award. I also want to thank the Academy for giving me this opportunity to make a few observations. I will briefly reminisce on some of my experiences in the early days of the semiconductor industry, with the Apollo program, and in the conversion of telecommunication networks to all digital operation. I will end with a few comments on my current concerns about information technology.

My professional career began when I joined Bill Shockley's organization at Bell Labs in Murray Hill, New Jersey, in March of 1952. This was the organization that evolved from the group that invented the transistor in 1947. When I arrived at Murray Hill most of the world's knowledge of transistor technology still resided in that building. Most of the original cast of contributors was still there.

In April of 1952 a symposium on transistor technology was held for Western Electric licensees. The objective was to provide enough information to the 40 attendees to "enable qualified engineers to set up equipment, procedures, and methods for the manufacture of these products." I was asked to organize a laboratory session in which the attendees, in small groups, could measure the characteristics of transistors, specifically point contact transistors, the structure in which Bardeen and Brattain first observed the transistor effect. For most of the students this would be the first time they had actually seen a transistor.

I had arrived from England just a month earlier. I was used to a climate that made a gradual transition from winter to summer during a period called spring. To my surprise, New Jersey that year went from winter to summer in one day, and I suddenly found myself exposed to temperature and humidity levels that were totally new to me. That transition took place two days before the start of the symposium. Murray Hill at that time was not air conditioned. When I got to the lab that morning, I found that my transistors for the session had lost all of their electrical characteristics—the CRT traces were flat! I had discovered for myself what many people already knew. The transistor was sensitive to its environment and particularly to humidity.

The lack of reliability of the early transistors was a huge setback and embarrassment to the semiconductor community. The transistor had been lauded as a device with no failure mechanisms, with nothing to wear out. Instead we had a severe reliability problem, one that took another 14 years to solve completely.

In early 1952 there were two known transistor structures, the point contact transistor and the grown junction transistor. Both were proven to work, but neither of them was reliable or suitable for large-scale manufacture. Thus, having invented the transistor, the challenge remained to find ways to design a product that would be reliable and easy to manufacture. This phase took the industry approximately another eight years, during which many challenging problems were addressed and fundamental solutions developed. This was an industry-wide effort. Although many of the early advances came from Bell Labs, companies such as GE, TI, Fairchild, and others made major contributions.

The substantial completion of this effort was heralded by the development at Fairchild of the planar transistor. This structure brought it all together. All the key development and engineering problems were either solved or on course for elegant solutions. Thus, by 1960 there was a sound foundation for the long-term manufacture of semiconductor devices. The resulting devices would eventually, by a process step added in 1966, be solidly reliable. And all this could be done with batch processing with the promise of high yield and low unit cost. Some 13 years after its invention, the transistor finally had a sound engineering foundation. The planar transistor also provided the base for the next giant step, the development of the integrated circuit, which was invented in 1958.

To my mind there were two outstanding characteristics of this industry-wide effort. The first was the constant search for understanding. The industry strongly believed in the importance of basic understanding and in avoiding the empirical approach, albeit resorting to empirical techniques as long as no basic solution existed. This belief has remained with the industry. Even during the many years when empirical solutions were applied to the reliability problem, the search for a basic solution continued and eventually won out. The second characteristic was a willingness to share information. Although the semiconductor industry from its beginning was highly competitive, it operated with an unusual willingness to share information. This attribute has also remained with the industry, as exemplified by the technology road maps produced regularly under the guidance of the Semiconductor Industry Association.

In 1964 I transferred from Bell Labs to Bellcomm, an AT&T subsidiary established in Washington, D.C., to provide systems engineering support for the Apollo manned space flight program. We prepared the top-level specification for the Apollo program. I will recount just one anecdote from this experience.

When I first became involved in the Apollo program, there was much discussion on how to specify reliability as it related to mission success and crew safety. There was strong support for the conventional approach of specifying reliability in terms of probabilities with long strings of "nines," and there were many debates on how long a string of nines was appropriate for a particular phase of the program. At a NASA management meeting one day, Wernher von Braun expressed his skepticism about this approach by asking the following question. Are you telling me that an astronaut, when leaving home in the morning, should kiss his wife goodbye on the doorstep and say "Dear, the probability of my being home for dinner is 99.999 percent"? Wernher had a wonderful ability to get to the heart of any matter. In the end, NASA chose to include two simple statements in the top-level documentation for Apollo: "no single failure will cause loss of a mission" and "no two failures will cause a loss of crew." These two statements had a profound influence on the manner in which the program was designed and executed and represent an elegant example of how program requirements can be expressed.

In 1971 I returned to Bell Labs in charge of the Network Planning Division. This organization was responsible for system engineering studies of the AT&T networks. At about that time it was recognized that the technology was at hand to permit the conversion of the networks to all digital operation; that, in turn, would lead to significant enhancements of the services that could be provided and the reliability of all network services. The conversion would require not only the design of new digital systems, both transmission and switching, but also a major reconfiguration of the network itself. It was also decided that the new systems should be substantially controlled by software. There were many challenges to be met. Today I will highlight some of those in switching.

The new machines were to have a switching fabric that would handle digital traffic and would be controlled by a stored program processor, which was, in effect, a special purpose computer. AT&T had a specification governing the reliability of switching machines in their network, a maximum of "two hour's downtime in 40 years." This may seem somewhat quaint today. Why not one hour of downtime in 20 years or three minutes per year? I believe the intent was to specify two things—the percentage of time a machine could be down and that the switch should be designed to provide service for 40 years. Indeed, the machines that were introduced in the early 1970s are still providing service today.

This is another example of a policy statement that has a powerful impact on all aspects of a project. For example, the only way we knew how to meet the downtime requirement was to provide dual processors simultaneously running identical programs.

Another major challenge resulted from the fact that the software contained several million lines of code, which was large for those days. Perhaps only IBM and some government projects required development of software of this size. We in the industry learned some painful lessons about developing software as it became clear that the difficulty increased rapidly with the size of the program. It was, therefore, highly desirable, where possible, to partition programs into smaller modules with clean interfaces so each module could be checked independently of the others.

We also recognized the benefits, both in development cost and customer satisfaction, of detecting and correcting program bugs as early in the process as possible, preferably in the design phase before the program was transferred for manufacture. The least desirable occurrence was for a bug to be found in the field.

Looking back on these experiences, I am impressed by how much of our efforts as engineers is dictated by the quality and reliability standards required to meet customer needs.

I will end with some observations on a development that has taken place largely since I retired, that is, the rapid expansion of the use of personal computers connected to the Internet. The growth in the size of the user community and the range of available services has been spectacular. However, I have a concern that, without further improvement in the usability and dependability of these systems, future growth in the customer base and of new features may be unnecessarily limited. I will briefly explain my concerns.

In the case of personal computers, the problems I see are not in the hardware but are substantially in the software. Personal computer programs crash, machines hang, programs perform illegal operations, and programs interact with one another in unpredictable and harmful ways. I spend much more time than I should trying to deal with these problems on my computer. I suppose, in a way, I enjoy the intellectual challenge as I do in solving crossword puzzles, but sometimes it can be frustrating. My wife asks how, if I have such difficulties, "ordinary" people are supposed to manage. And that is the heart of the issue. I expect that most of the people in this audience are able to deal with these problems, but I suspect that the great majority of people, including potential future users, could not cope with these difficulties, even if they plucked up the courage to try! If this situation persists, surely a large number of people will be excluded, or will exclude themselves, from full participation. And that would be unfortunate.

Speed of access to the Internet is another problem. It has been reported that about 75 percent of customers are still connecting via modems and thus are limited to a maximum speed of 56 kb/s. At my house, five miles from the telephone office, I never see more than 24 kb/s. Until we have a readily available, cost-effective solution to the provision of much higher access speed, the use of existing services and the expansion of new services will surely be limited.

The problem I see with Internet services themselves stems from the poor design of many Web sites, another software problem. This particularly lessens the effectiveness of making transactions via the Internet. With a few exceptions, I prefer not to carry out transactions over the Internet, because, in my experience, when they work, Internet transactions often take too long. Frequently, however, they do not work. There are other means of carrying out electronic transactions that can be faster and more dependable. I suspect that the majority of potential users would be even more reluctant than I to put up with this slowness and lack of dependability. Incidentally, there are many Web sites that *are* easy to use and are dependable. So the problem can be handled if the determination exists.

Clearly this whole enterprise is going through a period of reassessment. The financial markets are taking a much more realistic view of what it takes for an enterprise to be attractive to investors. Similarly, there are now more realistic reports on the extent of the use of Internet services, much more realistic than some of the extravagant forecasts made earlier.

If my concerns are well founded, perhaps now is a good time to address the need for easier use and more dependability. Since many of the solutions depend on the application of existing engineering principles and practices, I believe we engineers have an obligation to speak up. Perhaps there is also a role for engineering associations and, possibly, this Academy.

Again I wish to thank the NAE for honoring me with the Arthur M. Bueche Award and for the opportunity to make a few observations today.

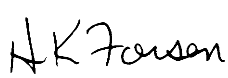
Foreign Secretary's Report

Harold K. Forsen

This year we elected eight exceptional foreign associates. The six who were able to attend the Annual Meeting and the induction ceremony indicated that they were very pleased and honored to be recognized by the NAE. I was very pleased to attend a reception for two of the electees from Denmark, held at the Danish embassy and hosted by His Excellency Ulrik Federspiel, the Danish ambassador. The official celebration reflects the importance the Danish government places on the NAE and is an indication of how our Academy is perceived by many countries. A breakfast for new and visiting foreign associates was attended by President **Wm. A. Wulf, Lance Davis,** and officers of the NRC. The occasion provided an opportunity for informal discussions on research and many other subjects of common interest.

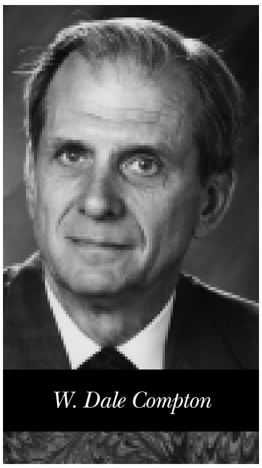
The German American Frontiers of Engineering (GAFOE) program in Essen, Germany, on October 10–12, 2001, was a great success. The program included four subject areas: (1) minimally invasive diagnostics and interventions; (2) intelligent transportation systems; (3) intelligent engineering in urban environments; and (4) energy and the environment. A thought-provoking after-dinner speech on globalization by Dr. Hans Olaf Henkel, president of Leibniz Gemeinshaft, had the audience asking questions for more than an hour. A tour of the Ruhr area the next day included visits to abandoned coal mines and coke processing plants that had been converted into museums, art displays, and conference centers; at the same time, enough historical hardware had been preserved to give visitors an idea of the magnitude of the operation and the working conditions of the era.

Attendance from the United States was down a bit (23 of 32 were able to attend), and some of those who could not make it were speakers. By the quick action of the NAE program officer Janet Hunziker, substitutes were found, and everything went off smoothly. We were also pleased to have a representative from Hungary, nominated by the Hungarian Academy of Engineering, attend as an observer. This was the first GAFOE sponsored and partially organized by the Alexander von Humboldt Foundation through the Transatlantic Science and Humanities Program, and we look forward to working with the foundation in the future. GAFOE 2002 will be held in Washington, D.C., in May 2002.



Harold K. Forsen
Foreign Secretary

Home Secretary's Report



W. Dale Compton

Dear Colleagues:

We want the members of the NAE not only to be the best in their fields but also to represent the broad spectrum of the engineering profession. To ensure that we identify and fully embrace newly emerging disciplinary and interdisciplinary areas of engineering, the Council has established an ad hoc peer committee to seek nominations of leading individuals in these areas. For the next two years the committee will accept and evaluate nominations of individuals in the forefront of four broad areas.

- **Bioinformatics:** mathematical/computational biology; functional genomics/proteomics; and the application of engineering to advance biology as a quantitative/information technology.
- **Nanotechnology:** microelectromechanical systems (MEMS); nanoelectromechanical systems (NEMS); nanobiotechnology; nanomaterials; nanomechanics; molecular computing; and molecular self-assembly.
- **Earth Systems Engineering:** sustainable development; environmental engineering; and global change assessment.
- **Integration of Smart Operational Systems:** adaptive and autonomous systems and their risks and safety; human-machine interfaces; and the integration of information technology in air traffic management, health care delivery, supply chain management, nuclear power systems, robotics, remote sensing and operations, and other areas.

The members of the ad hoc committee are:

Uma Chowdhry, *chair* (materials engineering)
DuPont Engineering

Michael L. Corradini (electric power/energy systems)
University of Wisconsin-Madison

Steven D. Dorfman (aerospace)
Hughes Electronics Corporation, retired

Sangtae Kim (chemical engineering)
Eli Lilly and Company

Way Kuo (industrial, manufacturing, and operational systems)
Texas A&M University System

Louis J. Lanzerotti (special fields and interdisciplinary engineering)
Bell Laboratories, Lucent Technologies

Douglas A. Lauffenburger (bioengineering)
Massachusetts Institute of Technology

Noel C. MacDonald (electronics engineering)
University of California, Santa Barbara

Thomas J. O'Neil (petroleum, mining, and geological engineering)
Cleveland-Cliffs, Inc.

Albert P. Pisano (mechanical engineering)
University of California, Berkeley

Sosale S. Sastry (computer science and engineering)
University of California, Berkeley

Julia R. Weertman (materials engineering)
Northwestern University

Loring A. Wyllie, Jr. (civil engineering)
Degenkolb Engineers

Nominations of individuals for consideration by the ad hoc committee should be sent to <*uma.chowdhry@usa.dupont.com*>

W. Dale Compton
Home Secretary

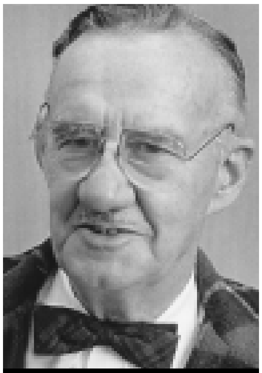
Bernard M. Gordon Prize for Innovation in Engineering and Technology Education

Bernard and Sophia Gordon respond to speeches in their honor after receiving a framed copy of the first ad for the Gordon Prize. Photo: Cole Bellamy.

More than 100 people gathered in Boston on October 16 to honor Bernard and Sophia Gordon, who have underwritten the NAE's Bernard M. Gordon Prize for Innovation in Engineering and Technology Education. The purpose of the prize—which was made possible through a gift of stock valued at $10 million—is to encourage and reward engineering educators who have introduced innovations in engineering and technology education.

The evening was hosted by **Norman Augustine**, current chair of the National Academies Philanthropy Council and former NAE chairman. The gathering included members of the NAE Council, the Gordon Prize Committee, directors of the NAE Center for Engineering Education, and staff members of Analogic Corporation, of which Mr. Gordon is both founder and chairman. **George Fisher**, current NAE chairman and retired chairman and CEO of Eastman Kodak, spoke to the group about the challenges of innovation in engineering education from his perspective as an engineering innovator, an employer, and a former student. NAE President **Wm. A. Wulf** discussed the role of the Gordon Prize in the NAE's overall engineering education program and presented the Gordons with a framed copy of the first published announcement of the Gordon Prize. The first prize will be awarded in February 2002.

Inventing Success One Challenge at a Time



Wilson Greatbatch

Wilson Greatbatch is a success by anyone's standards. The inventor counts the first human heart pacemaker among his 240 U.S. patents. He leads six companies. And at 82, he is researching ways to harness the energy of nuclear fusion to make travel to Mars a reality within his grandchildren's lifetimes. Yet ask him about his greatest accomplishment, and he'll tell you it's his ability to communicate with fourth graders. He figures he's chatted with about 1,000 of them through the years, often about what happens when the nuclei of two kinds of atoms are fused.

> *"Every time I fail, I feel good because I learned something."*
>
> —Russ Prize co-winner Wilson Greatbatch

"If you can't explain nuclear fusion to a fourth grader, then you really don't understand it," he contends.

Greatbatch spent several days on the Ohio University campus in early October to fulfill an obligation he incurred in February when he and fellow pacemaker pioneer Earl Bakken were named corecipients of the first **Fritz J. and Dolores H. Russ Prize**. The $500,000 prize, presented by the National Academy of

Engineering, which is awarded in recognition of engineering achievements that improve the human condition, was made possible by a multimillion-dollar endowment to Ohio University by 1942 engineering graduate Fritz Russ and his wife, Dolores.

During his stay, Greatbatch presented a public lecture on travel to Mars via nuclear-powered spaceships, met with Russ College of Engineering department chairs and representatives, and visited with undergraduate classes. One of his primary messages was: Success may be great, but so is failure.

"Don't fear failure," he says. "Failure is a learning experience. Every time I fail, I feel good because I learned something."

Greatbatch understands the importance of persevering. In the barn behind his house in New York, he built 50 pacemakers by hand using his own savings. Ten of those pacemakers were implanted in humans. In 1960 he founded Wilson Greatbatch, Inc., so he could dedicate all of his energies to pacemaker development. After he licensed his pacemaker to Minneapolis-based Medtronic, Inc., cofounded by his fellow Russ Prize recipient, it quickly gained clinical acceptance throughout the medical world. In 1983, the National Society of Professional Engineers recognized the achievement as one of the major contributions to society during the previous 50 years.

When asked whom he admires, Greatbatch answered, "Edison is a hero of mine, and he has more than 1,000 patents. I figure if I get one a week, I will catch up to him in 70 years."

Adapted from an article by Jennifer Kirksey Smith, Ohio University

Campaign Update

The NAE has been making good progress in its fund-raising drive to support the 1999 Strategic Plan. In its first two years, the Campaign for the National Academies, conducted jointly with the NAS and IOM, has raised nearly $170 million. By the end of 2001, the NAE expects that gifts and pledges will total more than $32 million, some to increase the NAE endowment and some to launch important new programs.

In this time of national crisis, the engineering community's intellectual support for antiterrorism is more important than ever. At the same time, we must continue to work on other critical issues, including educating a qualified and diverse workforce, improving technological literacy, and ensuring sustainability. Full funding for the NAE Strategic Plan will enable us to meet those challenges. Four new gifts from NAE members reflect our members' dedication to the Academy and its goals.

- **William (Bill) Friend**, NAE treasurer and retired executive vice president of the Bechtel Group, has added a pledge to his previous gifts, bringing his commitment to $100,000.

- Rear Admiral **Robert Wertheim** has completed a Charitable Gift Annuity to benefit the NAE. The annuity will provide a life income, and the remainder will be added to the NAE endowment.

- **Dale Stein**, president emeritus, Michigan Technological University, has made a bequest designation to support the NAE through his estate. The gift will provide unrestricted support for the NAE.

- A new grant from the **Elizabeth and Stephen D. Bechtel, Jr., Foundation** will support the Public Understanding of Engineering Program, which encourages professional engineering societies to coordinate their activities and messages to the general public.

Letter to President Bush

On September 20, 2001, the presidents of the National Academies sent a letter to President George W. Bush describing its decision to convene small groups of top scientists and security specialists in the next few weeks to consider how researchers can help head off terrorist threats. The full text of the letter is reprinted below:

September 20, 2001

The Honorable George W. Bush
President of the United States of America
The White House
Washington, DC 20500

Dear Mr. President:

The tragic events of September 11 demand the attention of all Americans. As we enter a new war against terrorism—one that will demand a focus on the complex interplay between technological, sociological, and political issues—the National Academies stand ready to provide advice and counsel in any way that the nation desires.

Our nation and the world have just received a terrible wake-up call. As in the 1940s, we have a new opportunity to mobilize many of the best of our scientists and engineers in a great common effort—one in which their knowledge and talents have been redeployed and tightly refocused on preventing the future attacks of terrorists. As part of that effort, we must completely reassess all of the potential threats to our nation.

Over the next few weeks, we will be convening small groups of senior national experts—both security specialists and scientists—for a series of private meetings. These nongovernmental groups will begin to explore the new dimensions of terrorism, and they will be asked to propose ways to marshal the enormous intellectual capacity of the scientific and technological communities of the United States to respond to our new threats. Unfortunately, one can easily invent scenarios that could cause far greater damage to our nation than the tremendous shock that we just received.

Members of three recent bipartisan congressional commissions have suggested an active role for the National Academies in facilitating a more concerted and better coordinated involvement of the U.S. scientific and technology community in assessing threats, developing countermeasures, and designing responses to terrorist incidents. We are committed to providing assistance to you and the nation. We will communicate to you the outcome of our initial analyses of the needs and opportunities as soon as possible.

Sincerely yours,

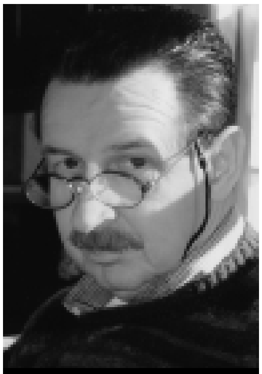
Bruce Alberts
President
National Academy of Sciences

Wm. A. Wulf
President
National Academy of Engineering

Kenneth Shine
President
Institute of Medicine

A list of recent Academy publications related to terrorism and security is available at <*http://www.nap.edu/feature.html*>.

New NAE Staff


Jack Fritz

Jack Fritz was appointed senior program officer for engineering and environment. He comes to the NAE from the World Bank, where he was a senior environmental engineer in the East Asia Environment Unit. His primary focus was on environmental, energy, and infrastructure projects in East and South Asia and Latin America. In the 1980s, Dr. Fritz managed international energy and environmental programs at the U.S. Agency for International Development (USAID), the National Research Council, and several consulting firms. He was also the engineer of record for two municipal waste-to-energy projects in New York.

Dr. Fritz received his Ph.D. in environmental engineering from the State University of New York at Buffalo, his M.B.A. in quantitative analysis and finance from the University of Cincinnati, and a B.S. in mechanical engineering from Rochester Institute of Technology.

In Memoriam

BORIS BRESLER, 81, affiliated consultant, Wiss, Janney, Elstner Associates, Inc., died on March 9, 2000. Mr. Bresler was elected to the NAE in 1979 for his pioneering work on the structural design of large works to withstand combined stresses, sustained loads, corrosion, fires, and earthquakes.

FRANK W. DAVIS, 86, retired president, Convair Aerospace Division and Fort Worth Division, General Dynamics Corporation, died on July 15, 2001. Mr. Davis was elected to the NAE in 1967 for the design, development, and testing of supersonic aircraft and missile systems.

MICHAEL L. DERTOUZOS, 64, professor of computer sciences and electrical engineering and director, Laboratory for Computer Science, Massachusetts Institute of Technology, died on August 27, 2001. Dr. Dertouzos was elected to the NAE in 1990 for his creative leadership in computer science, technology, and education.

DANIEL C. DRUCKER, 83, graduate research professor of engineering sciences, emeritus, University of Florida, died on September 1, 2001. Dr. Drucker was elected to the NAE in 1967 for his research on stress measurement and plastic deformation.

CLAUDE R. HOCOTT, 91, professor emeritus, University of Texas, died on September 9, 2001. Dr. Hocott was elected to the NAE in 1974 for his contributions to increased oil recovery through petroleum reservoir engineering, including fluid dynamics, phase behavior, and geochemistry.

MAURICE MAGNIEN, 81, chairman, Association for the History of Electricity in France, died on July 22, 2001. Mr. Magnien was elected a foreign associate of the NAE in 1979 for his leadership in advancing the development of the electrical power system of France.

ALEC W. SKEMPTON, 87, professor emeritus of civil engineering, Imperial College of Science, Technology, and Medicine, died on August 9, 2001. Sir Skempton was elected to the NAE in 1976 for his leadership in the study and practice of geotechnical engineering.

Calendar of Upcoming Meetings and Events

2001

November 6	NRC Governing Board Executive Committee
November 6–7	NRC Governing Board
November 7	Engineering Deans Council Executive Meeting
November 8	NAE Nominating Committee
November 19	Committee on Engineering Education
November 28	NAE Program Committee Meeting
November 29	CWE Web Advisory Subcommittee
November 30–December 1	Steering Committee of the Engineer of 2020
December 3	National Engineering Exploring Committee
December 4	Governing Board Executive Committee
December 6	Covering the Homeland War on Terrorism Media Workshop
December 7–8	2002 Election Committee on Membership Irvine, California
	Committee on Technological Literacy
December 12	Engineering and the Environment
December 17	Engineering and Society

2002

January 15	Governing Board Executive Committee
January 17	Symposium on Technological Literacy
January 23–24	Forum on Diversity in the Engineering Workforce Irvine, California
January 24–25	Committee on Diversity in the Engineering Workforce Irvine, California
January 28	Engineering Education Research Retreat
January 29	Finance and Budget Committee
February 4–5	NRC Governing Board Irvine, California
February 5	NAS/NAE Council Dinner Irvine, California
February 6	NAS/NAE Officers Breakfast
	NAS/NAE Council Meeting Irvine, California
February 6–7	NAE Council Meeting Irvine, California
February 8	NAE National Meeting Irvine, California
February 12	Governing Board Executive Committee
	NAE/ASEE Engineering Deans Colloquium
February 18	2002 NAE Reception for Awards Recipients Mayflower Renaissance Hotel, Washington, D.C.
February 19	2002 NAE Awards Dinner and Presentation Ceremony Union Station, Washington, D.C.
February 22	NAE Regional Meeting San Diego, California
March 1–3	U.S. Frontiers of Engineering Symposium (tentative) (rescheduled from September 13–15, 2001) Irvine, California
March 5	NAE Regional Meeting Austin, Texas
March 12	Governing Board Executive Committee
March 18	NAE Regional Meeting Madison, Wisconsin

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

National Research Council Update

New Federal Standards for Storing Coal Waste

According to the Board on Earth Sciences and Resources of the Division on Earth and Life Studies, the federal government should have the authority to review the stability of basins designed to store liquid waste from coal processing plants. Regulatory agencies should also work toward establishing a standard design to prevent the barriers between basins and underground mines from collapsing. Congress requested this study after a coal waste impoundment in Inez, Kentucky, failed last year, releasing 250 million gallons of waste that flowed through an underground mine into nearby creeks and rivers, including some that supplied water to the local community.

The study concluded that the current regulation of basins is less rigorous than the regulation of embankments. To remedy this, the Mine Safety and Health Administration (MSHA) and the Office of Surface Mining (OSM), both federal regulatory agencies, should have the authority to review the stability of basins. The agencies also should keep abreast of impoundment strategies and technologies used in other mining industries. The study also provided several other recommendations: federal standards should be implemented to set the minimum distance between basin and mine locations to help prevent breakthroughs; old mines and impoundment sites should be located (remote sensing and geophysical technologies can be used to search for abandoned underground mines); MSHA and OSM should work with relevant state agencies to set standards for surveying and mapping mines to ensure that proper measures are taken, and the maps should be archived digitally; the length of the review process for both new and existing impoundment permits should be shortened, and the current fragmented review procedures should be combined into a single process; the two agencies should establish a single system for assessing the risk of existing and proposed embankments; and 24-hour monitoring of certain basins should be required to provide timely warning of impending failures. The committee concluded that many of the alternatives to impoundment are promising, but also costly and dependent on local geography. Further studies on alternatives to impoundment will be necessary.

NAE members on the study committee included **Franklin M. Orr, Jr.**, Stanford University, who served as committee chair, and **Norbert R. Morgenstern**, University of Alberta. The full text of the report, *Coal Waste Impoundments: Risks, Responses, and Alternatives,* is available from National Academy Press and online at <*http://www.nap.edu/catalog/10212.html/*>.

Evaluating Oil Tanker Designs for Environmental Damage Control

In a new joint study by the NRC Transportation Research Board, the Marine Board, and the Committee on Evaluating Double-Hull Tanker Design Alternatives, a new method is offered for comparing oil tanker designs in terms of the amount of environmental damage they would cause in a grounding or collision. Assessing tanker performance before ships are built would encourage the development of innovative designs that would decrease environmental damage.

The methodology assesses a ship's chances of causing an oil spill by analyzing three features: the amount of structural damage and oil loss that would result from a specific collision or grounding; the environmental consequences of the spill; and how those figures would compare with a vessel of similar size but different design in the same type of incident. The committee used advanced computer modeling and simulation to arrive at values for comparison. After modeling and simulating different spill scenarios, the committee concluded that the amount of environmental damage from an oil spill is not directly related to the amount of oil that is spilled. Small spills were found to cause a disproportionately higher amount of environmental damage, gallon for gallon, than one would expect. In an already heavily damaged environment, extra oil causes less relative harm than in a pristine environment.

The committee recommended that the U.S. Coast Guard establish a procedure for submitting designs for consideration and standards against which new designs can be compared. The Coast Guard should also propose the new methodology to the International Maritime Organization so that all tankers can be uniformly evaluated.

NAE member **J. Randolph Paulling**, University of California, Berkeley, was a member of the study committee. The full text of the report, *Environmental Performance of Tanker Designs in Collision and Grounding: Method for Comparison* (TRB Special Report 259), is available online at <*http://www.nap.edu/catalog/10199.html/*>.

Technology Options for Destroying Chemical Weapons

Two reports by the Committee on Review and Evaluation of the Army Chemical Stockpile Disposal Program concluded that technologies being considered as alternatives to the Army's baseline incineration system for destroying mustard agent munitions at the Pueblo Chemical Depot in Colorado must all overcome technical challenges before they can become operational. The technologies—a modified form of incineration and two nonincineration alternatives—are all capable of destroying the chemical agent, but they all need additional engineering and development work before they can be considered ready to process the assembled chemical weapons stored at the Pueblo site.

In *A Modified Baseline Incineration Process for Mustard Projectiles at Pueblo Chemical Depot*, the committee identified a number of changes that would be necessary and further tests on the modified incineration process that was first tested at the Johnston Island facility for it to be a viable option for destroying mustard agent munitions at Pueblo.

The second report, *Analysis of Engineering Design Studies for Demilitarization of Assembled Chemical Weapons at Pueblo Chemical Depot*, assesses two alternatives to the incineration of chemical weapons: (1) hydrolysis followed by biodegradation; and (2) supercritical water oxidation. Both technologies can destroy mustard agent by using water or a base to break the chemical's molecular bonds.

As a signatory to the international Chemical Weapons Convention treaty, the United States has agreed to destroy its stockpile of aging chemical weapons—primarily mustard agent and nerve agents—by April 29, 2007. It is uncertain, however, whether the stockpile can be completely destroyed by this deadline.

NAE members serving on this committee include **David H. Archer**, Carnegie Mellon University; **James F. Mathis**, ExxonMobil Corporation (retired); **Frederick Pohland**, University of Pittsburgh; and **Kenneth F. Reinschmidt**, Stone & Webster, Inc. (retired). *A Modified Baseline Incineration Process for Mustard Projectiles at Pueblo Chemical Depot* is available online at <*http://www.nap.edu/catalog/10181.html*>), and *Analysis of Engineering Design Studies for Demilitarization of Assembled Chemical Weapons at Pueblo Chemical Depot* is available online at <*http://www.nap.edu/catalog/10182.html*>. Both reports are also available from National Academy Press.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are 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 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.)*

2001 Assessment of the Office of Naval Research's Aircraft Technology Program. This annual review evaluates six areas of the Aircraft Technology Program: integrated avionics, propulsion and power, air vehicle technology, unmanned aerial vehicles/unmanned combat air vehicles, survivability, and special aviation projects. The report recommends that the program develop a long-range strategic plan for naval aircraft that would provide a framework for future ONR investments and a vision for new capabilities, including affordable advanced air vehicle concepts. Paper, $18.00.

A Strategic Vision for Department of Energy Environmental Quality Research and Development. The under secretary of the U.S. Department of Energy (DOE) asked the National Research Council to recommend ways DOE could broaden its focus and adopt a more long-term strategic view for its environmental quality (EQ) portfolio. Current R&D includes activities to improve scientific understanding and develop new approaches to improving EQ. This report recommends criteria for evaluating the adequacy of the environmental quality portfolio and the principal elements of the portfolio, addresses the question of whether the portfolio should focus on environmental problems outside DOE related to EQ strategic goals, and recommends ways to determine the level of future investments in R&D. Paper, $38.50.

Classifying Drinking Water Contaminants for Regulatory Consideration. In the third report of the Committee on Drinking Water Contaminants, the committee explores how priorities should be set to identify contaminants that pose the greatest threats to public health. The committee evaluates, expands, and revises, as necessary, the conceptual approach to generating future drinking water candidate contaminant lists (CCLs) and related conclusions and recommendations in the second report. The report also explores the feasibility of developing mechanisms for identifying emerging microbial pathogens for research and regulatory purposes. The committee stresses the need for expert judgment in all CCL-related processes and for a conservative approach that errs on the side of protecting public health. Paper, $42.00.

Embedded, Everywhere: A Research Agenda for Networked Systems of Embedded Computers. This report, sponsored by the Defense Advanced Research Projects Agency and the National Institute of Standards and Technology, identifies opportunities for using embedded computers (EmNets), examines how EmNets differ from more traditional systems, and identifies research topics that should be addressed. The report provides a research agenda to guide federal programs related to computing research and inform the research community about the challenges of this emerging area of research. Issues related to the components of embedded computers and system-level issues are also discussed. Paper, $35.00.

Looking Over the Fence at Networks: A Neighbor's View of Networking Research. Based on a workshop at which more than half of the attendees were researchers in other fields, this report provides a new approach to the development of research agendas in key areas of information technology. The approach involves exploring how research can overcome the obstacles to realizing a vision for the future in which the Internet would provide a higher quality of experience and accommodate more diverse interests. The goal of the report is to stimulate fresh thinking in the networking research community. Paper, $12.00

Naval Mine Warfare: Operational and Technical Challenges for Naval Forces. This study, requested by the Chief of Naval Operations, examines issues related to both countermining and future sea mining capabilities. The recommendations include the establishment of mine warfare as a major area of naval warfare; greater emphasis on intelligence, surveillance, and reconnaissance; the reestablishment of a naval mining capability; and the modernization of the dedicated force for mine countermeasures. Paper, $44.75.

Observations on the President's Fiscal Year 2002 Federal Science and Technology Budget. This report endorses the administration's method of analyzing the science and technology (S&T) budget but expresses concerns about the distribution of the fiscal year 2002 budget. The committee calls on Congress to ensure that the government adequately supports S&T across agencies to help the country meet its national goals in defense, energy production and conservation, environmental protection, and economic growth. Paper, $12.00.

Review of the Future of the U.S. Aerospace Infrastructure and Aerospace Engineering Disciplines to Meet the Needs of the Air Force and the Department of Defense. This report recommends that an Air Force deputy chief of staff position be established with primary responsibility for overseeing all Air Force scientific and technical resources; the new deputy chief of staff would be the advocate for funding science and technology requirements and would ensure that adequate funding is budgeted annually. Other recommendations address the issues of technical personnel, expenditures and investments, the establishment of partnerships with industries and universities and their faculty members, and the reform of Civil Service rules for scientific and technical personnel. Paper, $18.00.

Review of the U.S. Department of Defense Air, Space, and Supporting Information Systems Science and Technology Program. This report recommends that the Air Force continue to increase its investment in science and technology (S&T) to twice its FY01 level; take action to strengthen S&T representation and advocacy at the corporate policy and decision-making level of the Air Force; request that Congress extend the pilot program for revitalizing the service laboratories by at least three years; and work to enact targeted modifications of Civil Service rules that directly affect the quality and health of the S&T workforce. The study was sponsored by the deputy under secretary of defense for science and technology. Paper, $18.00.