Engineering Mechanics and Materials Research in the Information Technology Age

Ken P. Chong and Daniel C. Davis
Directors, Mechanics and Materials Programs
Division of Civil and Mechanical Systems
Directorate for Engineering
National Science Foundation, Arlington VA 22230, U.S.A.

Introduction

The National Science Foundation (NSF) has supported basic research in engineering and the sciences in the United States for a half century and it is expected to continue this mandate through the next century. As a consequence the United States is likely to continue to dominate vital markets because diligent funding of basic research does confer a preferential economic advantage (Wong, 1996). Concurrently over this past half century, technologies have been the major drivers of the U. S. economy, and as well, NSF has been a major supporter of these technological developments. According to the NSF Assistant for Engineering, Eugene Wong, there are three *transcendental* technologies (Wong, 1999):

- Microelectronics – Moore's Law: doubling the capabilities every two years for the last 30 years; unlimited scalability; nanotechnology is essential to continue the miniaturization process.
- Information Technology – NSF and DARPA started the Internet revolution about three decades ago; confluence of computing and communications.
- Biotechnology – molecular secrets of life with advanced computational tools as well as advances in biological engineering, biology, chemistry, physics including mechanics and materials.

By promoting research and development at critical points where these technological areas intersect, NSF can foster major developments in engineering. The solid mechanics and materials engineering (M&M) communities will be well served if some specific linkages or alignments are made toward these technologies. Some thoughtful examples for the M&M communities are:

• Bio-mechanics/materials	• Simulations/modeling
• Thin-film mechanics/materials	• Micro-electro-mechanical systems (MEMS)
• Wave Propagation	• Smart materials/structures
• Nano-mechanics/materials	• Designer materials

Considerable NSF resources and funding will be available to support basic research related to these technologies. These opportunities will be available for the individual investigator, teams, small groups and larger interdisciplinary groups of investigators. However, most of the funding at NSF will continue to support unsolicited individual investigator proposals on innovative "blue sky" ideas.

In addition to NSF, there is also a sense that U. S. Federal agency research support is increasingly being driven by broad systemic initiatives. One of these initiative is *Information Technology* (IT), listed above as one of the *transcendental* technologies. The President's Information Technology Advisory Committee (PITAC) advises that an "immediate and vigorous information technology research and development (R&D) effort in Information Technology be initiated. IT is essential for the United States to have economic growth and prosperity in the 21^{st} Century." PITAC (www.ccic.gov) concluded that current U. S. Federal support for research in IT is inadequate and these current efforts also take "a short-term focus for immediate returns." PITAC recommends IT R&D with long term priorities focusing on "software development that is far more usable, reliable, and powerful, scalable information infrastructures that satisfy the demands of large numbers of users, high-end computing systems with both rapid calculation and rapid data movement, and IT education and training for the citizenry." Achieving these ends requires diversified modes of research support to foster projects of broader scope, longer duration and emphasis on projects involving multiple investigators over several years. Of most importance is using these new information technologies to advance critical application domains for the benefit our nation.

Discussion

Consistent with this theme, the National Science Foundation Directorate for Engineering in collaboration with other NSF Directorates and Federal agencies recently announced several IT-related initiatives. The NSF Directorate for Computer and Information Science and Engineering (CISE) and the Directorate for Engineering in cooperation with Division of International Programs jointly announced the *Wireless Information Technology and Networks* initiative (Program Announcement NSF 99-68) in early 1999. "The great demand for Internet services, wireless cable television distribution, and information technology, makes the development of broadband wireless mobile communication systems a national imperative in the 21^{st} Century." Researchers face many technical challenges, but "data rates of tens of megabits per second (enabling broadband Internet access, for example) are apparently realizable in the near future."

The Engineering Directorate research initiative on *Engineering Microsystems: "XYZ on a Chip"* (Program Announcement NSF 99-31) focuses on non-electronic applications of microelectronic technologies and exploration of non-electrical processes at the micro-scale. Here *XYZ* refers to any non-electrical phenomena such as "biology, genomics, chemistry, optics, mechanics, materials, sensors, actuators, and software." Examples of solid mechanics and materials engineering *XYZ* related phenomena could include MEMS, nanomechanics, etc.

The initiative *Engineering Sciences for Modeling and Simulation-Based Life-Cycle Engineering* (Program Announcement NSF 99-56) is a collaborative research program by NSF and the Sandia National Laboratories (Sandia) focusing on advancing the fundamental knowledge needed to support advanced computer simulations. This collaborative initiative capitalizes on the missions of both organizations. NSF's mission is to advance the fundamental science and engineering base of the United States. Sandia has the responsibility to provide solutions to a wide range of engineering problems pertinent to national security and other national issues. It is moving toward engineering processes in which decisions are based heavily on computational simulations; thus, capitalizing on the available high performance computing platforms. This FY 99 initiative has sought modeling and simulation advances in key engineering focus areas such as thermal sciences, mechanics and design. This initiative will continue for one more year and the authors of this paper should be contact for updates on status.

The NSF-wide research initiative, *Biocomplexity: Research on the Functional Interrelationships between Microorganisms and Biological, Chemical, Geological, Physical and Social Systems*, is a long-term effort to support “integrated research on the functional interrelationships between microorganisms and the biological, chemical, geological, physical, and/or social systems that jointly comprise complex systems.” Understanding biological complexity requires sophisticated approaches of integrating scientists from a range of disciplines. These include: “biology, physics, chemistry, geology, hydrology, social sciences, statistics, mathematics, computer science and engineering (including mechanics and materials).” These collaborations cannot be constrained by institutional, departmental or disciplinary boundaries.

Since 70% of the U.S. economy is service oriented, *Engineering the Service Industry* (Wong, 1999) is a major challenge in terms of “scaleable enterprises, manufacturing/construction processes, transportation systems, healthcare delivery systems, process modeling and simulation, government services and others.” In spite of its importance, the service industry lacks a true science base. The objectives of software engineering are also applicable for the service industry as a whole (Wong, 1999). These include “quality control, graceful recovery from failure (forging systems), scalablity and performance.” An initiative on Scalable Enterprise Systems is being developed.

The NSF Civil and Mechanical Systems (CMS) Division is planning an initiative on *Model-based Simulation* (MBS) (Sack, 1999). Model-based simulation is a process that integrates physical test equipment with system simulation software in a virtual test environment aimed at dramatically reducing product development time and cost. This initiative will impact many civil/mechanical areas: “structural, geotechnicial, materials, mechanics, surface science, and natural hazards (e.g., earthquake, wind, tsunami, flooding and land-slides).” MBS would involve “combining numerical methods such as finite element and finite difference methods, together with statistical methods and reliability, heuristics, stochastic processes, etc., all combined using super-computer systems to enable simulations, visualizations, and virtual testing.” Expected results could be fewer physical testing, or at best, better strategically planned physical testing in the conduct of R&D. Examples of the use of MBS in research, design and development exist in the atmospheric sciences, biological sciences, and the aerospace, automotive and defense industries. The manufacturing of the prototype Boeing 777 aircraft, for example, was based on computer-aided design and simulation. This initiative should be announced in the future and the authors of this opinion paper should be contact for updates on status.

In the future one should expect the continued introduction of bold innovative research initiatives related to important national agenda such as the environment, civil and mechanical infrastructure, the service industry and the business enterprises.

The Challenge to M&M

The challenge to the mechanics and materials research communities is, “How can we contribute to these broad-base and diverse research agenda?” Although the mainstay of research funding will support the traditional programs for the foreseeable future, considerable research funding will be directed toward addressing these research initiatives of national focuses.

Mechanics and materials engineering are really two sides of a coin, closely integrated and related. For the last decade this cooperative effort of the M&M Program has resulted in better understanding and designed of materials and structures across all physical scales, even though the seamless and realistic modeling of different scales from nano-level to system integration-level (Fig. 1) is not yet attainable. In the past, engineers and material scientists have been involved extensively with the characterization of given materials. With the availability of advanced computing, and new developments in material sciences, researchers can now characterize processes, design and manufacture materials with desirable performance and properties. One of the challenges is to model short-term micro-scale material behavior, through meso-scale and macro-scale behavior into long term structural systems performance. Accelerated tests to simulate various environmental forces and impacts are needed. Supercomputers and/or workstations used in parallel are useful tools to solve this scaling problem by taking into account the large number of variables and unknowns to project micro-behavior into infrastructure systems performance, and to model or extrapolate short term test results into long term life-cycle behavior (Chong, 1999).

MATERIALS		STRUCTURES		INFRASTRUCTURE
nano-level (10^{-9})	**micro-level** (10^{-6})	**meso-level** (10^{-3})	**macro-level** (10^{+0})	**systems-level** (10^{+3}) m
Molecular Scale	***Microns***		***Meters***	***Up to Km Scale***
***nano-mechanics**	***micro-mechanics**	***meso-mechanics**	***beams**	*** bridge systems**
***self-assembly**	***micro-structures**	***interfacial-structures**	***columns**	*** lifelines**
***nanofabrication**	*** smart materials**	***composites**	***plates**	***airplanes**

Fig. 1. Physical scales in materials and structural systems

Acknowledgments and Feedback

The authors would like to thank their colleagues and many members of the research communities for their comments and inputs during the writing of this opinion paper. We would appreciate further feedback from the research communities at large. We can be reached by e-mail at: [kchong@nsf.gov] and [dcdavis@nsf.gov]. Information on NSF initiatives, announcements and awards can be found in the NSF website:[www.nsf.gov].

Disclosure and Copyright Policy

References

Chong, K. P. (1999) "Smart Structures Research in the U.S.", *Keynote paper*, *Proc. NATO Adv. Res. Workshop on Smart Structures*, held in Pultusk, Poland, 6/98, *Smart Structures*, Kluwer Publ., 37-44. See also *Elasticity in Engineering Mechanics* by A. P. Boresi and K. P. Chong (1999) John Wiley, New York, NY.

NSF (1998) "Long Term Durability of Materials and Structures: Modeling and Accelerated Techniques", NSF 98-42, National Science Foundation, Arlington, VA.

Sack, R. (1999) "Model-Based Simulation", white paper, National Science Foundation, Arlington, VA. See also: [www.eng.nsf.gov/cms/] for any update.

Wong, E. (1996) "An Economic Case for Basic Research", *Nature*, Vol. 381, 187-188, May.

Wong, E. (1999) "Engineering the Service Industry," www.eng.nsf.gov/engnews/1999, 5 pp.