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**American Academy of Mechanics**
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# SELECTION OF THE EDITOR

For this issue, we are reprinting the selections from the NSF Blue-Ribbon Panel on Simulation-Based Engineering Science, including the Table of Contents. The full report may be found in Acrobat PDF format at http://www.ices.utexas.edu/events/SBES_Final_Report.pdf.

# CONTENTS

# EXECUTIVE SUMMARY

S*imulation* refers to the application of computational models to the study and prediction of physical events or the behavior of engineered systems. The development of computer simulation has drawn from a deep pool of scientific, mathematical, computational, and engineering knowledge and methodologies. With the depth of its intellectual development and its wide range of applications, computer simulation has emerged as a powerful tool, one that promises to revolutionize the way engineering and science are conducted in the twenty-first century.

Computer simulation represents an extension of theoretical science in that it is based on mathematical models. Such models attempt to characterize the physical predictions or consequences of scientific theories. Simulation can be much more, however. For example, it can be used to explore new theories and to design new experiments to test these theories. Simulation also provides a powerful alternative to the techniques of experimental science and observation when phenomena are not observable or when measurements are impractical or too expensive.

*Simulation-Based Engineering Science (SBES)* is defined as the discipline that provides the scientific and mathematical basis for the simulation of engineered systems. Such systems range from microelectronic devices to automobiles, aircraft, and even the infrastructures of oilfields and cities. In a word, SBES fuses the knowledge and techniques of the traditional engineering fields—electrical, mechanical, civil, chemical, aerospace, nuclear, biomedical, and materials science—with the knowledge and techniques of fields like computer science, mathematics, and the physical and social sciences. As a result, engineers are better able to predict and optimize systems affecting almost all aspects of our lives and work, including our environment, our security and safety, and the products we use and export.

Whereas the use of computer simulations in engineering science began over half a century ago, only in the past decade or so have simulation theory and technology made a dramatic impact across the engineering fields. That remarkable change has come about mainly because of developments in the computational and computer sciences and the rapid advances in computing equipment and systems. There are other reasons. For example, a host of technologies are on the horizon that we cannot hope to understand, develop, or utilize without simulation. Many of those technologies are critical to the nation’s continued leadership in science and engineering. Clearly, research in SBES is quickly becoming indispensable to our country’s security and well-being.

This report was prepared by a Blue Ribbon Panel on Simulation-Based Engineering Sciences, which was convened by the Assistant Director of the Engineering Directorate of the National Science Foundation (NSF). The Panel was directed to explore opportunities for and potential advances in SBES and to make strategic recommendations as to how to structure programs to foster SBES.

The Panel developed its findings and recommendations from several information sources. Among them, interactions with recognized leaders of the computational engineering and science communities played an essential role. Another important source of information was the work of previous panels and committees. The results of those earlier efforts, which have accumulated over the last decade, address major issues in the computational and computer sciences. The Panel also relied on input from leaders in the computer simulation community who participated in the NSF-supported workshops on SBES. Finally, the Panel developed its findings and recommendations after thorough discussions among its members.

This report explores the potential impact of advances in SBES on science and technology and identifies the challenges and barriers to further advances in SBES. For instance, we must overcome difficulties inherent in multiscale modeling, the development of next-generation algorithms, and the design and implementation of dynamic data-driven application systems. We must improve methods to quantify uncertainty and to model validation and verification. We must determine better ways to integrate data-intensive computing, visualization, and simulation. Importantly, we must overhaul our educational system to foster the interdisciplinary study that SBES requires. The payoffs for meeting these challenges are profound. We can expect dramatic advances on a broad front: medicine, materials science, homeland security, manufacturing, engineering design, and many others.

For more than a decade, researchers and educators in engineering and science have agreed: the computational and simulation engineering sciences are fundamental to the security and welfare of the United States. The findings and recommendations of this report strongly reinforce that contention.

# MAJOR FINDINGS

1. SBES is a discipline indispensable to the nation's continued leadership in science and engineering. It is central to advances in biomedicine, nanomanufacturing, homeland security, microelectronics, energy and environmental sciences, advanced materials, and product development. There is ample evidence that developments in these new disciplines could significantly impact virtually every aspect of human experience.

2. Formidable challenges stand in the way of progress in SBES research. These challenges involve resolving open problems associated with multiscale and multi-physics modeling, real-time integration of simulation methods with measurement systems, model validation and verification, handling large data, and visualization. Significantly, one of those challenges is education of the next generation of engineers and scientists in the theory and practices of SBES.

3. There is strong evidence that our nation's leadership in computational engineering and science, particularly in areas key to Simulation-Based Engineering Science, is rapidly eroding. Because competing nations worldwide have increased their investments in research, the U.S. has seen a steady reduction in its proportion of scientific advances relative to that of Europe and Asia. Any reversal of those trends will require changes in our educational system as well as changes in how basic research is funded in the U.S.

# PRINCIPAL RECOMMENDATIONS

1. The Panel recommends that the National Science Foundation and other Federal research agencies make changes in their organizational structures to facilitate longrange core funding of SBES. The new Cyberinfrastructure at NSF is envisioned as a "portion of cyberspace" where scientists can "pursue research in new ways and with new efficiency" by utilizing: 1) high-performance, global-scale networking, 2) middleware, 3) high-performance computing services, 4) observation and measurement devices, and 5) improved interfaces and visualization services. Serious consideration should be given to the feasibility of developing a parallel program in SBES that interfaces to multiple divisions of NSF in concert with Cyberinfrastructure. Supporting SBES research should certainly be a goal of every division within the Directorate of Engineering at NSF, but the realization of the full potential of advances in SBES will require support across all directorates and from other federal agencies as well.

2. To maintain our leadership in science and engineering, the Panel recommends a minimum increase in NSF funding of $300 million per year over 2005 levels of SBES-related disciplines. We cannot maintain our leadership in engineering and the engineering sciences without substantial investments in SBES, because simulation is a key element in accelerating progress in engineering. Advances in computing speed alone or in measurement devices or in networking or interfaces cannot meet the great challenges before us without advances in the basic components of SBES. Similar observations have been made in the President's Information Technology Advisory Committee (PITAC) report, as well as in the results of several other related studies.

3. The Panel recommends a long-term program of high-risk research to exploit the considerable promise of SBES. The Panel strongly supports the observation made in the PITAC report and elsewhere that short-term investments and limited strategic planning will lead to excessive focus on incremental research rather than on longrange sustained research with a lasting impact. Progress in SBES will require the creation of interdisciplinary teams that work together on leading-edge simulation problems. The work of these teams should be sustained for a decade or more to yield the full fruits of the investment.

4. The Panel recommends that NSF underwrite the work of an NRC committee to explore the issue of interdisciplinary education in detail and to make recommendations for a sweeping overhaul of our educational system. The problem of education in SBES component disciplines, and in multidisciplinary programs in general, is large, pervasive, and critically important. The initiative for change will not likely come from academia alone; it must be encouraged by the engineering and scientific leadership and throughout the organizational structure of our universities.

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