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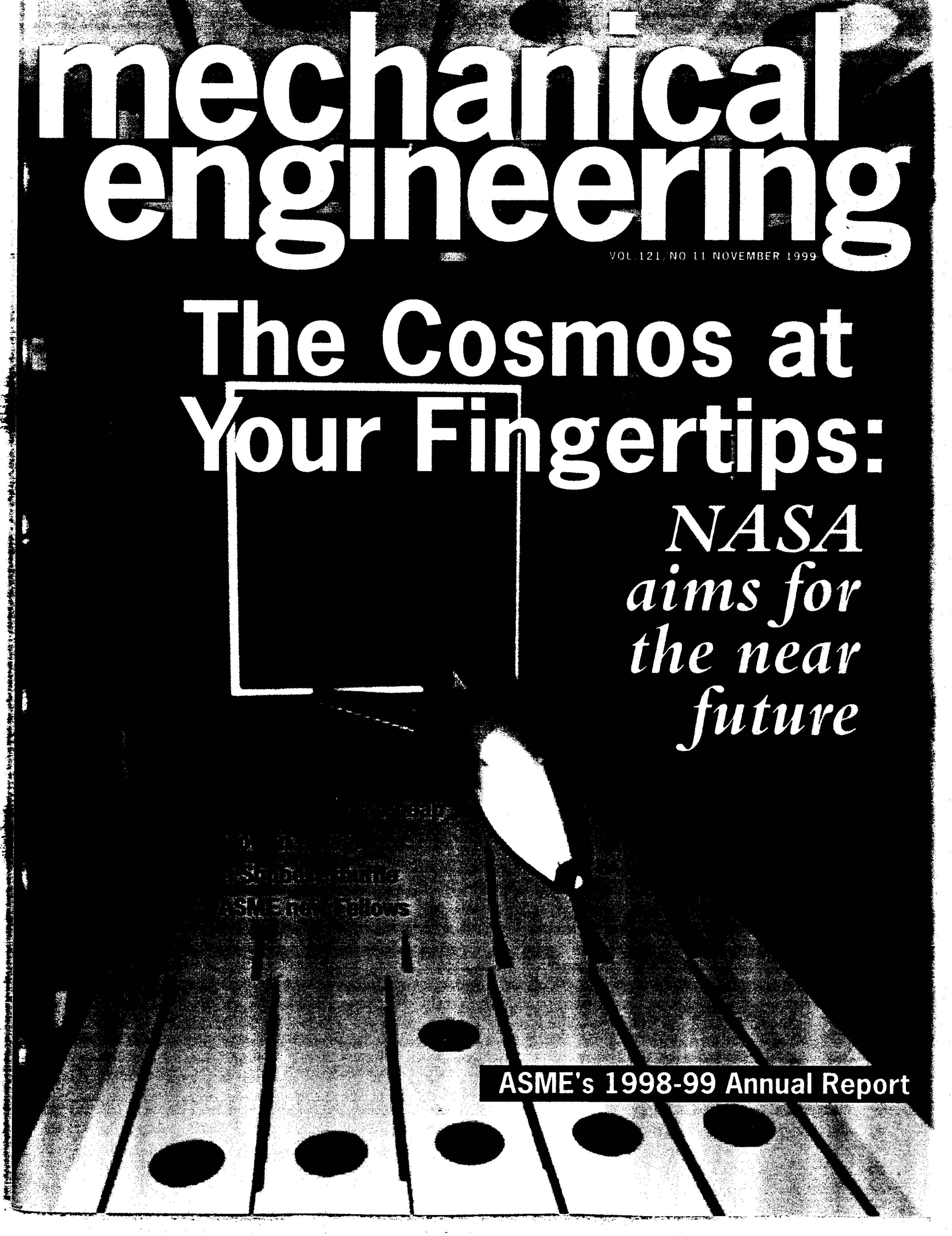
The Cosmos at Your Fingertips:

NASA aims for the near future



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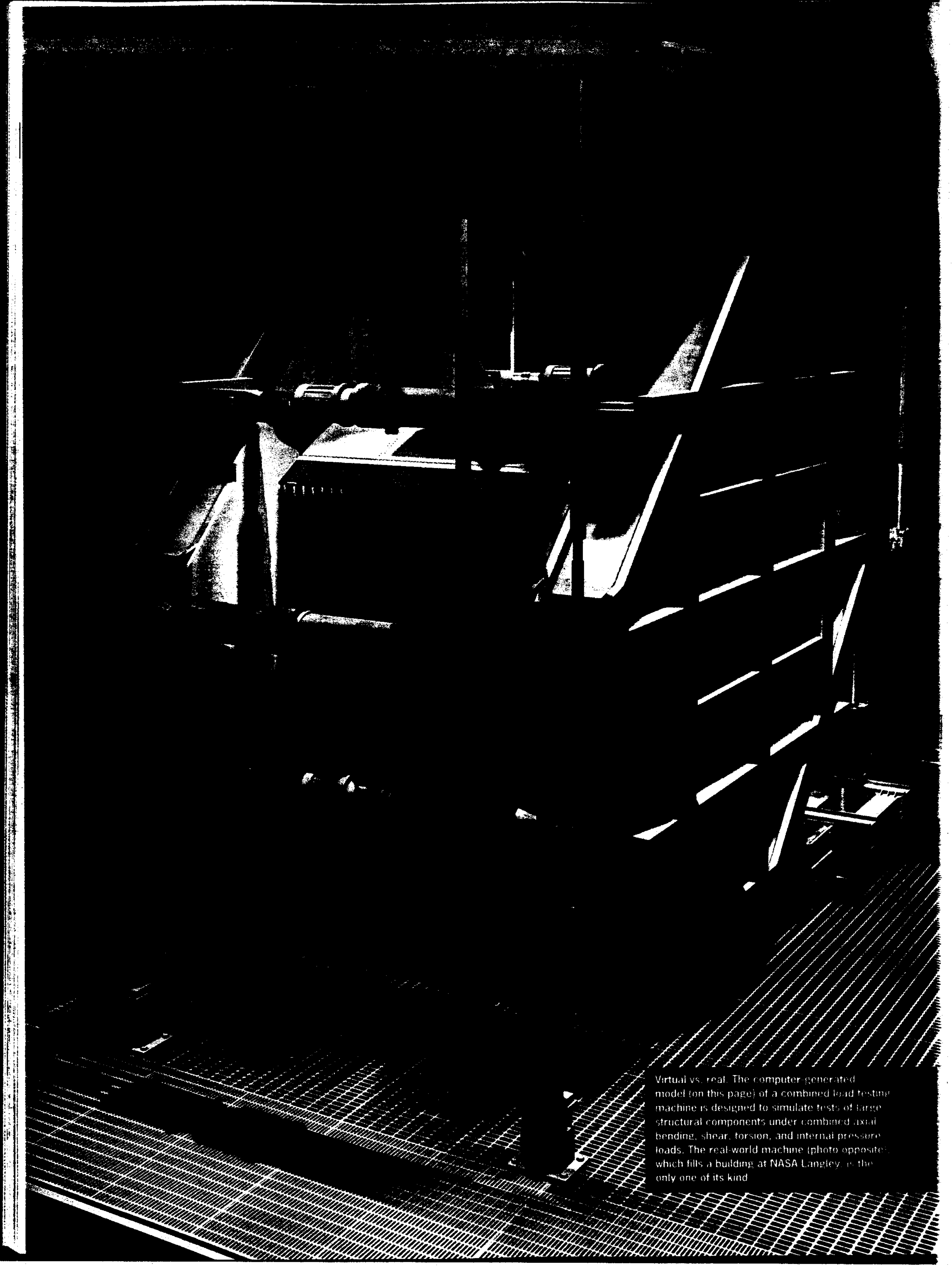
ASME new Fellows

ASME's 1998-99 Annual Report

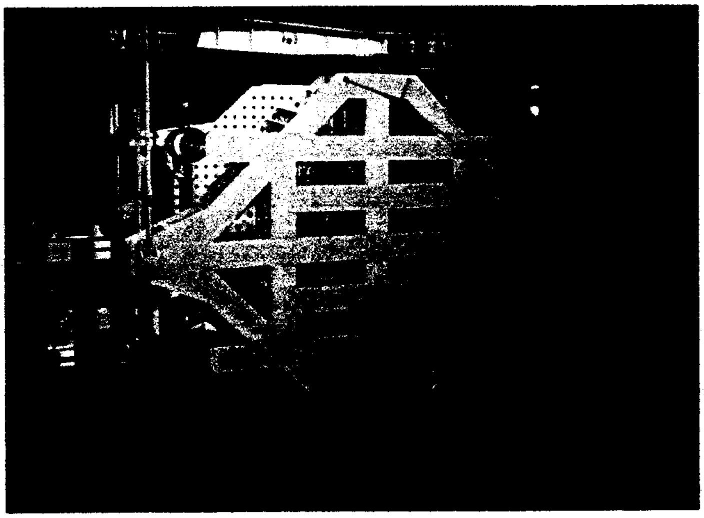


Virtual vs. real. The computer-generated model (on this page) of a combined load testing machine is designed to simulate tests of large structural components under combined axial bending, shear, torsion, and internal pressure loads. The real-world machine (photo opposite), which fills a building at NASA Langley, is the only one of its kind

READY FOR THE FUTURE?

NASA explores virtual environments that can bring work, creativity, and distant expertise closer together than ever before.

By Daniel S. Goldin, Samuel L. Venneri, and Ahmed K. Noor



RAPIDLY DEVELOPING TECHNOLOGIES and changing economic realities promise to have a profound impact on engineering environments and practice, as well as on engineering organizations, over the next few years. Among the influences taking shape today are the convergence of computing, communication, and information technologies; advances in modeling, simulation, and manufacturing technologies, and in knowledge-based engineering, the incorporation of artificial intelligence and expert systems into product development processes.

As a result of technological advances, globalization of markets, and heightened competitive pressures, the early 21st century will witness dramatic changes in the way high-tech engineering systems are designed, produced, operated, maintained, and eventually disposed of. Future environments will allow diverse, geographically dispersed teams to share and transform information into knowledge by combining and analyzing it in new ways. The interactive, multisensory, immersive environments will permit collaboration among experts in several engineering disciplines at widely distributed locations, and will enable them to rapidly apply novel technologies, create better products in less time, and better manage risks.

The potential benefits for product development and scientific research have led many organizations to initiate programs to design collaborative distributed virtual environments. Among these programs are Distributed Knowledge Environment of the Department of Defense; Knowledge and Distributed Intelligence of the National Science Foundation; Intelligent Collaboration and Visualization of the Defense Advanced Research Projects Agency; System Integration for Manufacturing Applications of the National Institute of Standards and Technology; and the two NASA complementary programs, Intelligent Synthesis Environment and Intelligent Systems.

The overall goal of NASA's programs is to revolutionize scientific research and engineering processes by creating a distributed collaborative environment that will enable the linking of design teams and scientists from NASA, industry, and universities in the creation and operation of aerospace systems and in synthesizing their missions.

The programs' broad framework also will be used for scientific research and product development in complex

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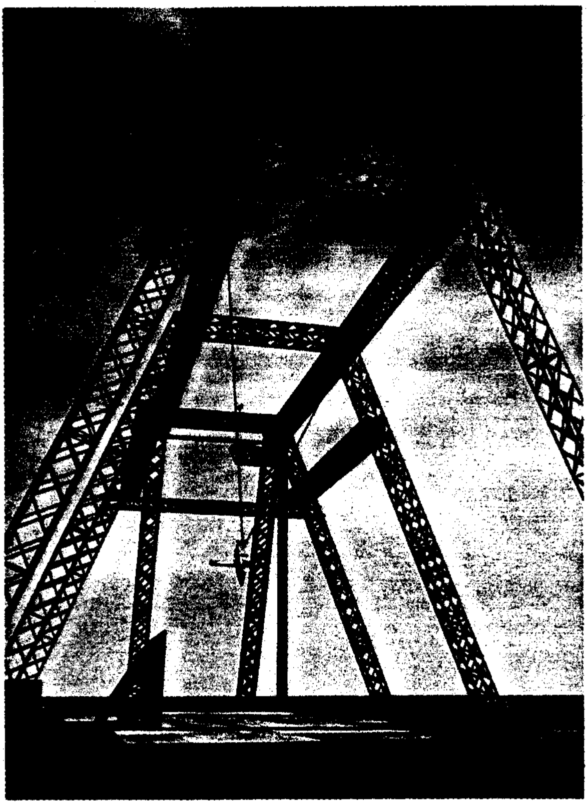
non-aerospace applications.

Realizing the full potential of collaborative distributed virtual environments like the one being developed under the ISE and IS programs entails educating and training engineering and science teams, not only in the component technologies, but also in new approaches for collaborative distributed synthesis and virtual product development within a global infrastructure.

TRAINING, EDUCATION, AND LEARNING

There has long been a philosophical gap between engineering education and training. Education's goal has traditionally been to impart high-level cognitive skills that would underpin lifelong learning. Training's goal was to bring performance up to a skill level that would let people successfully carry out new tasks. Recently, however, training began to emphasize the skills involved in lifelong learning, as evidenced by the growth of focused engineering workshops and online training facilities on the Internet. In a sense, both education and training objectives fit in the larger classification of learning activities.

Computer-based learning technology dates back to the 1960s. Passive computer-based instruction systems were built in the 1960s and 1970s. Later developments in that period included learner modeling and more elaborate computer-learner interfaces. Examples of computer-based instruction systems are the Plato system developed at the University of Illinois at Urbana-Champaign in 1960, and the IBM 1500 computer-assisted instructional system. Plato was one of the first programming environments for computer-based instruction that included text and graphics. IBM 1500 had an integrated learner terminal configuration providing a keyboard and light pen response mode, CRT-based graphics, audio, and static film projector.



A 3-D computer simulation of an impact dynamics facility can test airplanes and other flight craft for crash safety, including how design changes can protect passengers and increase their chances of survival.

The addition of expert systems to computer-based instruction resulted in the intelligent tutoring systems of the 1970s and 1980s. These systems had explicit models of tutoring and domain knowledge, and were more flexible in their response than computer-based instruction. However, they were developed for information transfer and were constrained to a single method of instruction and learning. The latitude of the learner in the early intelligent tutoring systems was highly circumscribed. The system typically selected the next task or problem, decided when the learner needed support and feedback in problem solving, and determined the nature of information the learner received. Systems of this sort include Sophie, the first to provide a simulation environment for debugging electronic circuits, and Steamer, used to train Navy personnel in the proper operation of steam propulsion plants.

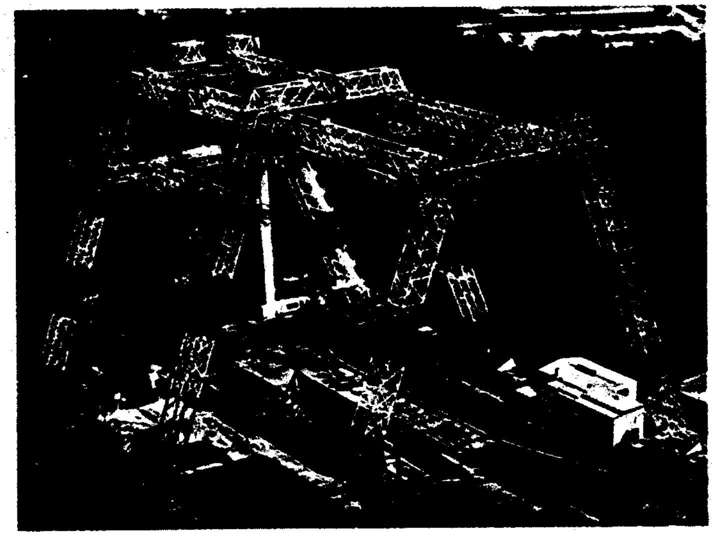
The advent of intelligent agents, which enabled the learner to manipulate cognitive artifacts from several perspectives or viewpoints, led to the interactive learning systems of the 1990s. The Department of Defense, NASA, other government agencies, and universities have developed systems. Advances in communication technology and the widespread availability of the Internet led to the development of online courses and other interactive learning systems with intelligent evaluation facilities.

Current interactive learning systems, although diverse, share four characteristics that distinguish them from intelligent tutoring systems: Learning is done by constructing knowledge rather than through lecture, or through organized drill-and-practice; the learner, rather than the instructor, is in control; individualization is determined by the learner, not by the instructor; and feedback is generated by the learner's interaction with the learning environment, not by the instructor's.

After decades of evolutionary change, revolutionary changes are both needed and possible for creating effective environments for life-long learning by engineering professionals. The change is driven by four categories of forces:

Developments in organizations and workplaces. In the 1980s, the focus of engineering organizations was on quality through reduction of defects and use of total quality management models. In the 1990s, the focus shifted to re-engineering and streamlining the processes through the use of virtual product development and enterprise resource planning. As we move from the industrial to the knowledge era, engineering organizations will make radical changes in their workplaces. They will use ultrapowerful processors, ultrahigh-capacity networks, and electronic performance support systems to create virtual organizations. The workplace will be transformed from the stationary offices centered around desktop computers and workstations into an intelligent networked environment that enables diverse, geographically dispersed teams to collaborate in real time in immersive multisensory environments. The needs of high-performance engineering organizations go well beyond current virtual product development and enterprise resource planning systems, and include high fidelity, end-to-end simulation of the entire life cycle of the product.

Economic pressures. To remain competitive, engineering organizations will move from mass production to mass customization. In addition, the rapid changes in technology will result in continuously changing requirements in the knowledge and skills of workers. The effective differentiator for an engineering enterprise will be its human intellectual capital—the sum of the understanding, skills, and competencies of its technological workforce.



NASA Langley maintains an impact dynamics research facility, 400 ft. long and 200 ft. high, to conduct crash testing of full-scale aircraft under controlled conditions, yielding data from onboard instruments and from cameras on the plane, frame, and ground.

Learner demographics. Because of the increasing number of older learners in the workplace, there is a need for just-in-time training, or on-demand training, a process in which the learner receives training at the time it is needed for performing a particular task. Flexible delivery systems, such as online intelligent, individually tailored courses, can be used for this purpose.

Growing interdependence among technology, workplace, and learning. Technology advances will have a more significant impact on workers than in the past. Technology will change the workplace by making learning and work synonymous, and will help in transforming high-tech engineering organizations into learning organizations. Life-long learning will become a vital responsibility at every level of engineering organizations. To remain competitive, engineering enterprises will have to provide a conducive learning environment in the workplace.

VIRTUAL ENVIRONMENTS, DIVERSE TEAMS

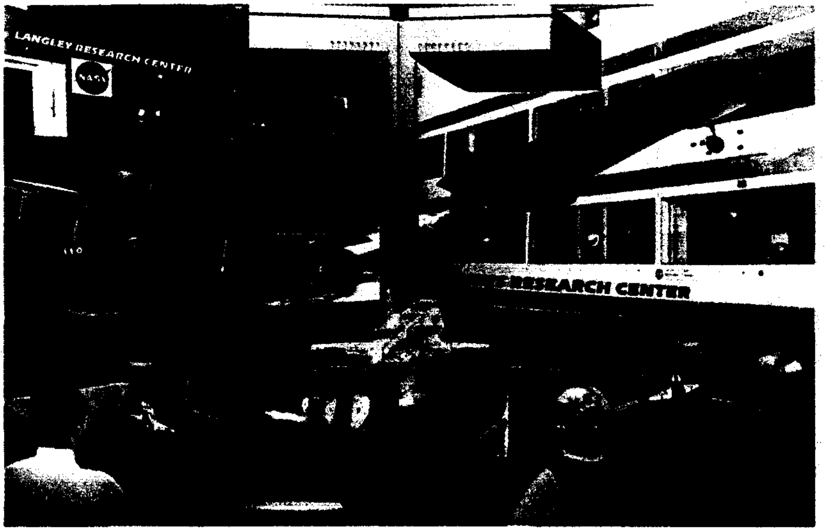
Two activities are performed as part of the ISE and IS programs to effect the cultural change needed to realize the potential of the programs. The first is development of Distributed Learning Environment, and the second is Simulation of Diverse Team Structures and Processes.

The Distributed Learning Environment aims at bringing current and future participants up to speed, not only in using component technologies, but also in new approaches for collaborative distributed mission synthesis and virtual product development by geographically dispersed, highly diverse teams. In addition to using powerful computing platforms and ultrahigh-capacity networks, the Distributed Learning Environment will incorporate state-of-the-art knowledge representation technologies that support the acquisition, storage, maintenance, retrieval, and application of digitally coded engineering knowledge and skill; tools for planning, deploying, and life-cycle management of learning; tools for learner performance assessment and support; and tools for rapid deployment of just-in-time learning using multimedia, immersive facilities, smart agents, and multisensory and reconfigurable interfaces.

Reconfigurable human computer interfaces take advantage of advances in cognitive neuroscience to couple humans with computers, and maximize the performance of both. Natural languages provide effortless communication with the computer, and the interfaces can be both adaptive and reconfigurable. Categories of interfaces that can be used to identify different states of mental alertness of the user include neural interfaces, based on brain waves (for example, alpha waves and mu waves), and biological interfaces using electromyographic signals. Once the computer identifies the user's state of alertness, it can automatically change the amount and format of the information presented.

Most of these facilities exist, but have not been combined in learning environments before. The Distributed Learning Environment will have dynamic, reusable instructional objects, that is, modules that can be selected to meet the individual learner's needs. It will enable learning anywhere and at any time, and will be used to create new and empowering adaptive learning strategies tailored to each individual learner's skills and needs. The environment will be characterized by the immersion of the learner in highly communicative multisensory interactions involving simultaneous visual, auditory, and haptic feedback. The use of multimedia and multisensory facilities will enable the learners to explore, analyze, and understand complex phenomena remote from their everyday experience, and can help in displacing intuitive misconceptions with alternative, more accurate mental models. The simulation facilities of the environment will enable the study of highly coupled multiphysics and multiscale phenomena, such as those associated with computationally driven materials development, from the nanometers of quantum mechanics to the meters of operational engineering systems.

Also, ISE/IS testbeds will be used for collaborative mission synthesis and product development projects at different engineering schools. The project teams consist of students from the participating institutions, and engineers and scientists from NASA and industry, all using the testbeds of ISE/IS. The collaborative multiteam projects will enable the teams to think beyond traditional engineering systems, seek inspiration from biological systems for augmenting the capabilities of current systems, and create adaptive thinking systems—systems that evolve, develop and learn, and are able to undergo modifications according to unanticipated environmental conditions or changing circumstances, without direct human intervention.



Technology is being developed that will let scientific and engineering team members follow, and interact with, distant physical experiments, while running real-time simulations of their own.

Taking inspiration from biological systems to achieve maximum capability for space exploration and communication, for example, mission planners are considering the concept of robotic outposts — a remote highly distributed scientific research station, operating autonomously using multiple robotic platforms cooperating in the manner of an ant colony.

The second activity, Simulation of Diverse Team Structures and Processes, is needed because collaborative distributed product development and mission synthesis involve complex interactions among diverse teams. The teams will be working in a highly heterogeneous environment (including different computing platforms, software systems, and multisensory immersive facilities) to organize and generate information and ideas. Simulating activities (such as data and information sharing), processes (such as generating and prioritizing alternative mission scenarios and decision making), and information flow

NASA's Distributed Collaborative Environment Vision

THE INTERNATIONAL SPACE STATION, the largest international technical venture ever undertaken, involving a range of complex activities by teams from 16 countries, marks an era of global partnerships in space science and exploration. It represents the next step in human space exploration and was enabled by the explosive growth in computing power and connectivity, which is reshaping relationships among engineers and organizations. This reshaping has prompted a cultural shift in engineering and scientific creativity.

But even the space station seems insignificant in contrast to some of NASA's goals over the next 25 years. In space science, they are characterized by sustained in-depth scientific studies at increasingly remote environments with themes as compelling as the search for life in the universe. The goals of these activities include a vigilant, intelligent robotic presence in the solar system; exploration of interstellar space; and discovery of Earth-like planets around nearby stars with a telescope powerful enough to determine signs of life 1,000 trillion miles away.

An integrated human-robotic exploration strategy is being developed, with the space station as a learning platform to prepare astronauts for visiting other planetary bodies. In earth science, a distributed network of scientific and environmental observation spacecraft will be integrated with terrestrial systems to provide long-term weather prediction and resource management on local, regional, and global levels.

The realization of those ambitious goals under current budget constraints requires new kinds of missions and space systems that use novel technologies and manage risks in new ways, as well as revolutionary changes in the way space systems are designed, manufactured, and operated, and in the way complex missions are synthesized. The NASA Intelligent Synthesis Environment and Intelligent Systems programs attempt to meet the needs of future systems and missions. The ultimate goal is to revolutionize engineering processes, scientific research, and lifelong learning. The seamless integration of teams, processes, and disciplines provided by ISE and IS will enable an end-to-end simulation of the product life cycle and mission scenarios before the mission begins.

Intelligent Synthesis Environment has five major components: rapid synthesis and simulation tools; cost and risk management technology; life cycle integration and validation; collaborative engineering environment; and cultural change—training and education.

Intelligent Systems has four major components: human-centered computing, which looks at the way humans learn and interact with each other, with computers, and with other machines; automated reasoning, which automates tasks in planning and control, learning, and software engineering; intelligent use of data, which helps people visualize, categorize, and understand information and generate knowledge; and revolutionary computing, which investigates the new hardware and software infrastructure that will be necessary to host these advanced intelligent systems on Earth and in space.

In addition, ISE and IS will leverage a number of other technologies developed by NASA, other government agencies, and industry, including high-performance computing, high-capacity communication and networking, human-computer interaction, information technology, and knowledge-based engi-

during these interactions, can help in training the teams, identifying guidelines for enhancing their performance, and improving decision making early on. It can also help in developing metrics to assess the effectiveness of the collaboration.

In addition, the ISE and IS programs will incorporate several technologies that can be used to significantly enhance the effectiveness of some of the advanced learning facilities.

VIRTUAL LABORATORIES AND CLASSROOMS

Several universities and commercial software vendors have developed facilities for simulating limited science experiments. However, little has been done on simulating large-scale engineering experiments. Modeling and simulation capabilities being developed as part of NASA's programs, coupled with the advances in microprocessors and visual computers with motion video instruction, are approaching real-time modeling. The University of Virginia's Center for Advanced Computational Technology will test the process in the near future to simulate physical experiments.

Work to date at the center has focused on the creation of a virtual structures laboratory (including combined load testing of large structural components), a virtual impact dynamics facility for crash simulations, and virtual wind tunnels. Intelligent software agents, advanced visualization engines such as Virtual Reality Modeling Language, and novel visualization paradigms such as computational steering (near real-time simulation, visualization, and control) will be used in these facilities. The synergistic coupling of near real-time physics-based system-level simulations with the physical in-the-loop testing of actual hardware components should significantly increase the knowledge generated by these experiments, and reduce the dependency on expensive and time-consuming full-scale system-level validation testing associated with complex engineering systems.

On-line training and virtual classrooms are typically used to provide learning environments with custom self-instruction, flexible tutorial support, and choice of both the place and time of learning. Three categories of facilities are used in these environments: namely, instruction, including multimedia lectures, links to other resources and tools for searching, browsing, and using archived knowledge; communication, including e-mail, UseNet, chat centers, video, and internet conferencing; and course management and performance evaluation.

In the future, the multisensory representation of complex engineering data through the combined use of visualization, haptic feedback, and sonification (the use of nonspeech audio to convey information) will significantly increase the bandwidth of the human-computer inter-

neering. The two programs represent a major cultural change in product development and mission synthesis. A number of application-specific testbeds will be developed to assess, validate, and achieve the vision for the distributed collaborative environment. These applications include new architectures, such as novel space transportation concepts, and missions for exploration of outer planets and interstellar space using multiple cooperating robotic platforms. The whole mission and system lifecycle phases will be simulated with the appropriate fidelity throughout the development and operational stages.

The successful implementation of the ISE and IS programs will enable the achievement of at least three objectives.

One is the creation of flexible engineering organizations, with multidisciplinary teams. The teams can be transformed into groups that are extremely focused on improving design synthesis and product engineering, and so overcome rigid structures such as hierarchical management.

Another objective is the better understanding and appreciation of different cultures—recognizing and managing the behavioral patterns that result from combining cultures with different languages.

And the third is providing the best talent and skill mix for each project—using virtual organizations so that the best combination of abilities is available anywhere.

Meeting the first objective requires simulating diverse team structures and processes. Meeting the second and third objectives requires formal training and technologies, such as real-time language translation. Some of these activities are part of NASA's programs.

At present, individual teams are working on planning various aspects of the ISE and IS programs. Implementations will be made early in fiscal year 2000, and significant progress is expected within the next two years. In the next decade, simpler, more efficient modeling and simulation tools, including a design language, will be made.

To realize the programs' full potential, researchers must address fundamental issues, such as human factors, group support processes and team dynamics, information security, and the costs and benefits of facilities and tools for a particular application class. There also must be attention to certification and validation. With the ISE and IS programs, future space and other high-tech systems with a hierarchy of intelligence are expected to achieve unparalleled levels of reliability and safety, but these systems will also present unprecedented levels of complexity and uncertainty.

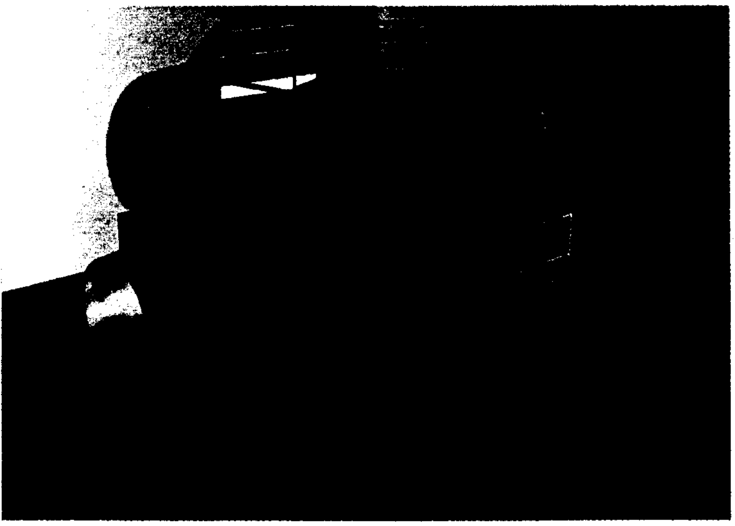
The ISE and IS programs will significantly influence scientific research, engineering, and learning processes. They will help to focus the learning on the quests for meaning and relevance. They will broaden the perspective of engineering professionals and assist them in dealing with the complexity and uncertainty of future systems. NASA will use large-scale application testbeds as one of the major mechanisms for working with universities, other government agencies, and industry to develop revolutionary, adaptable lifelong learning environments. These environments will synergistically couple leading edge technologies and significantly increase the achievement of the learners, as well as reduce both the time and cost of learning.

The creation of the new engineering culture and capabilities provided by ISE and IS will significantly affect the way new products are conceived, developed, manufactured, and operated.

Unparalleled levels of safety—and complexity.

face, and help in revealing underlying features that go unnoticed when only the mode of visualization is applied. The currently used WIMP (windows, icons, menus, pointing systems) interfaces will be replaced by knowledge-user interfaces, such as voice-activated personal-access devices with wireless communication, speed reading, and visual browsers, for improving communication and search capability.

The coupling of intelligent agents with feature recognition can lead to the development of a virtual instructor that recognizes reactions communicated, for example, through the facial expression and the vocal intonation of the learner, and provides an appropriate response. The learner can engage the virtual instructor in a two-way conversation in natural language, asking for details or background for the material covered. The interaction with the virtual instructor is more like face-to-face interaction and goes beyond menu-based and text-based interfaces. In addition, the advances in human-machine communication and cognitive neuroscience might provide the virtual instructor with more insight and understanding of human thought development. The virtual instructor can motivate learners emotionally as well as rationally. Emotion plays an important role in learning. The virtual instructor can free human instructors from the routine tasks associated with information transfer.



A computer model of the test section of the 8-foot high-temperature tunnel of NASA Langley. It is used for simulating physical wind tunnel tests.

ADVANCED LEARNING ENVIRONMENTS

The contributions of ISE and IS can be incorporated into three categories of advanced learning environments—expert-led group learning, self-paced individual learning, and collaborative learning—which, in combination, can reduce the time and cost of learning, and sustain and increase worker competencies in engineering organizations.

The human instructors in these environments will serve many roles, including inspiring, motivating, observing, evaluating, and steering the learners, both individually and in distributed teams.

The human instructors in expert-led distributed learning in a virtual environment serve as coaches, guides, facilitators, and course managers. Their presentations focus on giving a broad overview of the topic and its diverse applications, and they end their presentations with more penetrating, what-if questions that can enhance the critical thinking and creativity of the learners. Elaborate visualization and multimedia facilities are used in the presentations. Routine instructional and training tasks are relegated to the self-paced individual environment.

The individual learning environment engages the learner and provides a high degree of tailored interaction. It can be used for self-paced instruction of routine material not covered in the lecture. Such instruction can be enhanced by using virtual instructors assigned by the human instructors. It can be used to study physical phenomena that can be coupled with biological processes using advanced visualization, multimedia, and multisensory immersive facilities. The individual learning environment can serve to carry out virtual experiments—computer simulation of physical experiments.

Collaborative learning environments teach teamwork and group problem solving. Instructors and learners can be geographically dispersed. Eventually, they can be brought together through immersive tele-presence facilities to share their experiences in highly heterogeneous environments involving different computing platforms, software, and other facilities, and they will be able to work together on designing complex engineering systems, beyond what is traditionally done in academic settings. Because participants can be virtually collocated without leaving their industry and government laboratories, collaborative learning environments can enable the formation of new university, industry, and government consortia. Eventually, global learning institutions with multilingual facilities may be established, so that each subject is taught by its leading experts from around the world.

Programs for collaborative distributed environments can provide engineering schools with opportunities to restructure their learning strategies and establish a framework for engineering education that will meet the challenges of the next century. NASA will work with universities, other government agencies, and industry on the development of effective lifelong learning strategies and facilities that can expand the scope and quality of engineering research, and create new partnerships between diverse engineering and science communities.

The ultimate goal of these learning facilities is to create an intellectual environment where academic and experiential learning are effectively and efficiently commingled. In such an environment, academic rigor is learned in concert with professional job performance, and academic complexities are addressed within the industrial concern. The new learning environments will significantly increase creativity and knowledge, dissolve rigid cultural boundaries among engineering and science teams, and create high-performance knowledge teams that enhance the global performance of diverse organizations. ■