A CADRE of Engineering Computers at Caltech

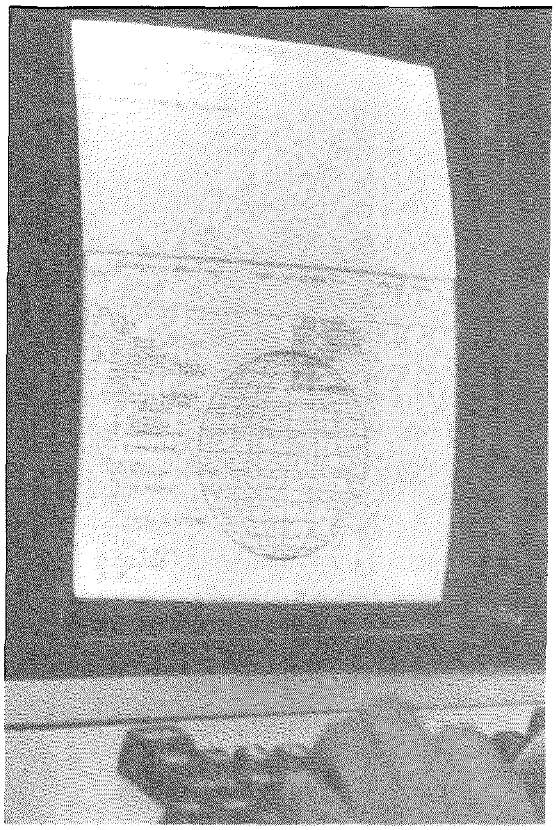
by Dennis Meredith

CHARLES BABCOCK enters the small room in Caltech's Guggenheim Laboratory, touches a few keys on the computer terminal and the screen comes to life. He specifies a program for constructing models on the computer screen. The computer then lists a number of basic shapes he can choose from to begin his modeling — including blocks, cylinders, ellipsoids, hexahedrons, hollow ellipsoids, spheres, tubes, curved surfaces, and quadrilaterals.

Choosing a cylinder, he specifies its size and orientation, and directs the computer to draw it. The computer pauses, and after a moment of calculation slowly traces the lines of a cylinder onto the screen. Babcock chooses another cylinder, specifies a smaller size, rotates it, and tells the computer to insert it into the first cylinder. Once more, he tells the computer to draw the figure, and after a few moments, traced upon the screen is the small cylinder, joined to the larger one at an angle.

Babcock experiments with different shadings, directs the computer to make the cylinder hollow, and — satisfied with his work — decides to try another figure. This time, he draws a simple square and tells the computer to extrude it through space, rotating it as it is extruded. The result is a hollow, square, warped tube.

Although these two figures were simple ones, Babcock could have used combinations of simple shapes, extrusions, and specified points in space, to draw *any* shape, from the simplest arrangement of pipes, to the most complex machine part. What's more, he could then use this three-dimensional model as the basis for a complex computerized engineering study — called finite element analysis — of the model. In this procedure, he would specify the points on the structure to be



used in the analysis and direct the computer to analyze how it might respond to loads. He could then tell the computer to show him visually how the model would warp in response to a given load.

The process is called computer-aided design, or CAD. In combination with the analytical power of computers, it is creating as profound a revolution in engineering as mathematical analysis did many decades ago. Such computer systems typically feature computer graphics hardware and software that visually display the progress of a design project. They also include engineering analysis programs that can perform complex calculations to determine how the real-life engineering product will behave under a range of circumstances.

Engineers in many industries now use CAD systems to design buildings, automobiles, aircraft, space probes, dams, highways, chemical plants, electrical circuits, computer chips, and any other projects requiring engineering analysis. They are also linking computer-aided design and manufacturing — creating "CAD/CAM" systems that, for example, use the design for a machine part produced on a computer to guide the production of that part by automated machine tools.

Like many of his Caltech engineering colleagues, Babcock, professor of aeronautics and applied mechanics, is now wrestling with how best to teach the powerful techniques of CAD to his students in mechanics.

It's a very active topic of conversation these days in Caltech's Division of Engineering and Applied Science, mainly because of a system, now in its early stages of development, known as CADRE — for Computer-Aided Design, Research and Education. The system development is overseen by a faculty committee chaired by Fred Culick, professor of applied physics and jet propulsion. This group of representatives from the various areas of the division is now planning CADRE as a major network of computers spread throughout the buildings of the engineering division. Although CAD is the current major focus of the effort, CADRE will ultimately encompass most of the division's computer resources for the use of computers in education and research.

Today, the system consists of two VAX minicomputers, running design software donated by the Ohio-based Structural Dynamics Research Corporation (SDRC). Eventually CADRE will consist of numerous computers, terminals, plotters, and other devices. The linked computers will provide a powerful set of tools, both for faculty research and student training in CAD.

There is no question but that engineering students at Caltech must be conversant with the new technologies, says Culick. Having the ability to visualize engineering problems and to feed in parameters and have results displayed in real time is profoundly affecting the way engineers approach engineering analysis. While engineers formerly had to figure out results from reams of paper printouts splattered with numbers, CAD brings an unprecedented freedom of conceptualization.

"If you're going to build a house, you specify the standard-size lumber — two-by-fours, for example — because that's what's available," says Culick. "It's the same with engineering analysis; you tend to bend the problem into a shape that allows you to use the analytical tools that are available." But once those tools come to include powerful number-crunching analytical programs that display their results in easy-to-grasp computer graphics form, the result will be great flexibility of engineering analysis.

To Babcock, another object of teaching CAD is to help students guard against unwise use of computers.

"In a way, we have to teach students about computers in order to vaccinate them against the machines. We can teach classical solutions to engineering problems, so the students will develop an intuitive feel for correct results that they can then use to make wise judgements." But numerical solutions to the classical equations can be as flawed when spit out of a computer as when incorrectly obtained by hand, a distinction computer-naive students may miss.

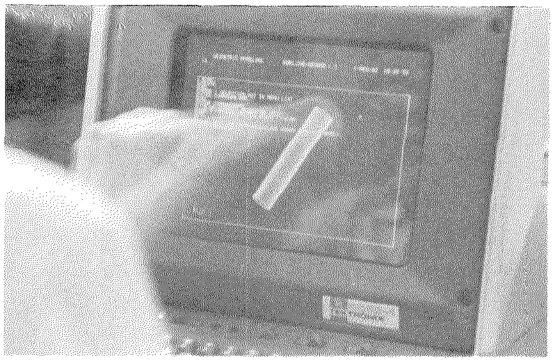
"If we don't expose them to computers here," says Babcock, "we'll find they go out into industry, start to use the computer, and often just start to do garbage. Thus, we hope to use computers partly to demonstrate how engineers can run into trouble."

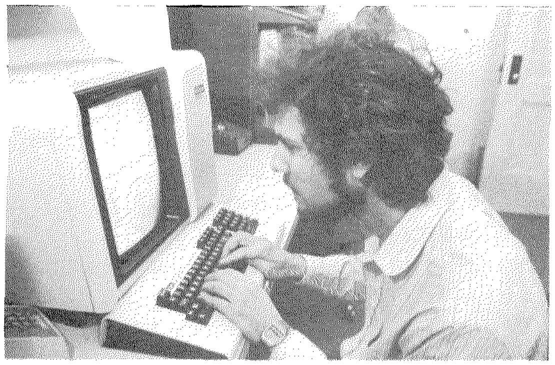
The seeds of CADRE were sown in 1979, when Culick became concerned that Caltech was behind in the teaching of CAD. His first task was to assure himself and his fellow educators that CAD possessed enough intellectual content to justify teaching it at Caltech.

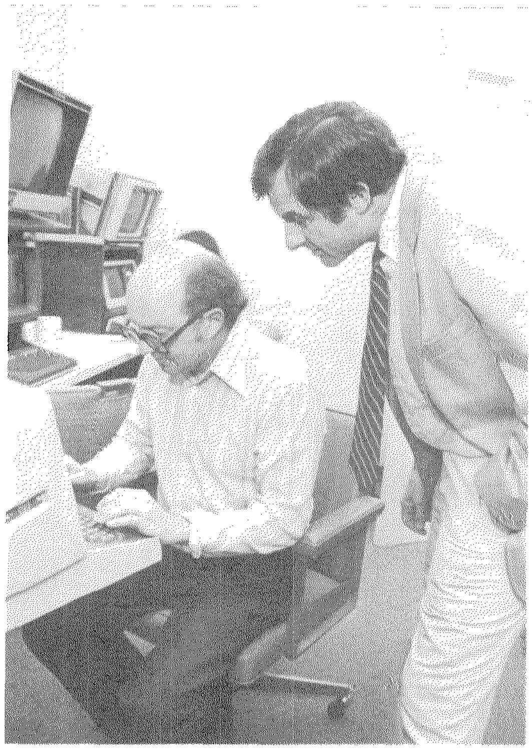
"We're not in the business of training people to go out and do routine tasks," says Culick. "To put it bluntly, Caltech is not a trade school. We had to be sure that CAD would be used to further the intellectual content of our coursework."

After attending meetings and workshops, Culick found that such universities as Ohio State, Rensselaer Polytechnic Institute, and the University of Michigan had established successful CAD systems for education, and that CAD was, indeed, a significant enough intellectual tool for Caltech to consider its own role in teaching the new technology.

"I quickly came to several conclusions," recalled Culick. "First, that the effort will require a great deal of money to do properly. Second, I saw that the large investment in CAD at those schools had become restricted to a small part of mechanical engineering — the area of mechanical design. The hardware and software required for CAD looked to me to offer much more novel, interesting applications than its use thus far had indicated."







Charles Babcock (left) and Fred Culick summon a cylinder to the screen with CADRE's geometric modeling program.

At a different terminal Jon Melvin (lower left) draws a sphere.

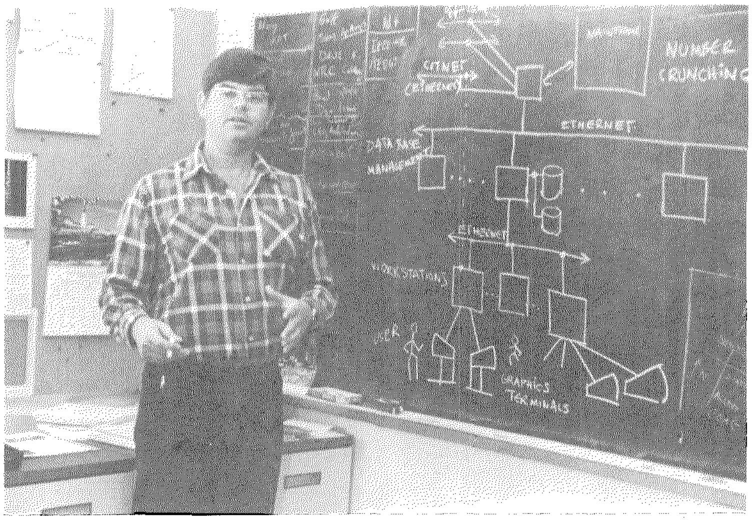
Culick also concluded that it would be far more efficient and useful for a small school like Caltech to plan a CAD system that could be used for both teaching and research. Thus, Culick and his colleagues envision CADRE as quite different from its counterparts at other universities.

"The most important difference may be that all fields in the division will be involved in the system — sharing software and use of hardware. This sharing may promote interdisciplinary exchanges not even forseen."

The next step in CADRE's formation came with the appropriation of $250,000 in Institute funds for the effort in the spring of 1981, a sum that Culick terms "only seed money." Using this money, the first hardware was purchased last summer, consisting of two Digital Equipment Corporation VAX computers, which were subsequently augmented with Tektronix graphics terminals and other necessary peripherals to form the first part of the larger CADRE system. The job of designing and implementing the initial configuration and integrating it into the future system as CADRE evolves, was taken on by Paul Dimotakis, associate professor of aeronautics and applied physics, and Jon Melvin, a part-time staff member of physics and engineering.

"We recognized at the outset," says Dimotakis, "that the problem of introducing computer-aided engineering tools has both near-term and long-term aspects. In the near term, we want to expose students and faculty to the existing technology in this area and make it available to them in both curriculum and research. So CADRE has to conform to existing software and hardware systems and standards to minimize the start-up time penalty. In the long term, we're confronted with a much more challenging problem. We have to recognize not only that CADRE may have to accommodate a technology that is advancing at a revolutionary rate, but also that these computer tools in engineering will probably affect engineering itself, and the way we think, in radical ways."

Anticipating at least one aspect of this problem, the CADRE network is designed to allow easy user access to different computers for different tasks. Instead of the traditional "star" network configuration — a central computer serving many users — that was dictated by computer characteristics in the 1970s, the CADRE system is being designed as a hierarchical distributed network of resources linked by high-speed Ethernet sub-networks. This complements the larger effort also currently under way at Caltech to provide a campus-wide computer network (supported by a grant from the Fletcher-Jones Foundation) that has already begun to provide services at selected sites on campus. The campus network should be operating on a much larger scale within 12 to 18 months. Dimotakis and Melvin are also trying from the start to design sufficient redundancy into the CADRE system to make it as resistant as possible to single-point failures.



Paul Dimotakis sketches CADRE's hierarchical architecture, in which a number of work stations, each serving one or more user terminals, are connected via Ethernet to data base management stations, which are joined in turn to the main computer. CADRE will also link up to the campus-wide network already under way, and a system of direct interconnections from the various levels will make CADRE fail-safe.

Not only will students and faculty have access to terminals in their offices and computer centers, but in the classrooms as well. Thus, a professor will be able to explore the possible solutions to a sophisticated engineering problem using real-time computer analysis, displaying the results on a large screen in the classroom. Culick expects profound effects on both engineering research and education due to the powers of CADRE.

"The way we teach and do research will change drastically in the next few years. Having easy-to-use distributed resources readily accessible to students and faculty will encourage that process," he says. "We expect much of the evolution of CADRE to come from students, and we'll be trying to provide an environment for students and faculty to work in, not just a facility with which faculty can show students how to use computers. Each year, what we do will probably be different from what we did the year before.

"Primarily because of the small size of Caltech, CADRE will offer truly unusual opportunities. With much less investment and support than required in other leading universities, we are able to create a unique environment for the applications of computers."

Even before the CADRE computers began functioning, however, Caltech engineering students had already begun training in CAD. For example, last year some 50 undergraduate mechanical engineering students in Associate Professor of Engineering Design David Welch's classes learned CAD on the terminals of the Pasadena-based computer-aided-design company CADRI, which is headed by Caltech graduate Louise Kirkbride (BS '75 Eng, MS '76 EE).

Early use of CADRE came this spring in a civil engineering course taught by James Beck, assistant professor of civil engineering and John Hall, research fellow and lecturer in civil engineering. Welch plans to use CADRE in his design courses beginning next fall.

Also this spring Dimotakis's AE 107c class, "Case Studies in Engineering," is focusing on computer-aided engineering, featuring speakers from SDRC, JPL, and Aerojet Electro Systems. During the course, students will receive hands-on experience in CAD using six graphics terminals operating in the first of CADRE's computer facilities in Thomas Laboratories. They'll use not only the enormous base of software donated by SDRC but also hardware and software donated by Tektronix, Inc. (Digital Equipment Corporation and Nippon Electric Corporation have also supplied equipment at special discount, and SDRC and Northrop Corporation have provided training.) Visitors from a number of other companies have also come to campus to discuss CADRE, and Culick and Dimotakis hope that the project will attract continuing participation by industrial personnel at the working level, in both education and research.

Despite such generous donations, future hardware and software for CADRE, Culick expects, will probably cost several million dollars. Annual operating costs, including adequate staff support, will be in excess of $200,000, he believes. He also believes, however, that "we must accept computer-aided engineering as a new responsibility of university education. If we're to continue to attract good students and faculty, and to offer a farsighted engineering education, we simply must have the very best capabilities for using computers. We've had excellent support from the Institute, as well as industry. We'll need both, as well as considerable intelligent planning, if we're to take full advantage of these remarkable tools." □