TECHNOLOGY

A New Industrial Revolution Is on the Way

by GENE BYLINSKY

An airplane is a plumber's nightmare. A DC-10, for instance, has three miles of hydraulic tubing that twists, bends, and turns throughout the airframe in triply redundant systems. Fabricating all that tubing used to involve a great deal of slow and expensive handwork. To begin with, it was necessary to construct a mock-up of an airplane's tubing, with craftsmen bending and fitting by hand as they went along. The sections would then be taken out and stored on warehouse shelves to serve as templates for subsequent pieces of tubing, which were also bent by hand.

Now master tubes are no longer stored on warehouse shelves. Instead, a designer routes replacement tubes from the computer memory where the descriptions reside. At the press of a button, he retrieves the key structural elements from the memory and then designs the needed section of a tube on the terminal screen with a fiber-optics light pen. At the press of another button, the needed section of tubing emerges from a computer-controlled tube-bending machine nearby.

The payoff from the new system has been remarkable. It's a lot more than just saving on warehouse space, although that in itself is substantial. The biggest benefit is that the tubes designed and fabricated under computer control fit into the airplane better, with fewer adjustments. When tubes were bent by hand for F-15 fighters at McDonnell Douglas three years ago, as many as 100 tubes per aircraft didn't fit. Now, using computerized tube-bending for F-18 fighters, McDonnell finds that only four tubes per aircraft have to be readjusted. As many as a dozen craftsmen used to bend tubes by hand for a single plane. Now the job takes three people: a man who watches over the tube-bending machine, and two tube assemblers. Most valuable of all is the saving in time. Typically, under the old system it took Northrop six weeks from release of engineering drawing to bent tube in hand. Elapsed time now: 18 minutes.

Research associate: Alicia Hills Moore

This is the world of CAD/CAM (Computer Aided Design/Computer Aided Manufacturing), where the future of manufacturing is being forged. If wisely and widely applied, CAD/CAM could overcome the productivity stagnation that has led to questions about the ability of American industry to remain competitive on the world scene. This modestly named technology, pioneered and developed in the U.S., has a power of explosive significance. Says a leading CAD/CAM specialist: "Revolution is an overused word, but that's what's going to happen here."

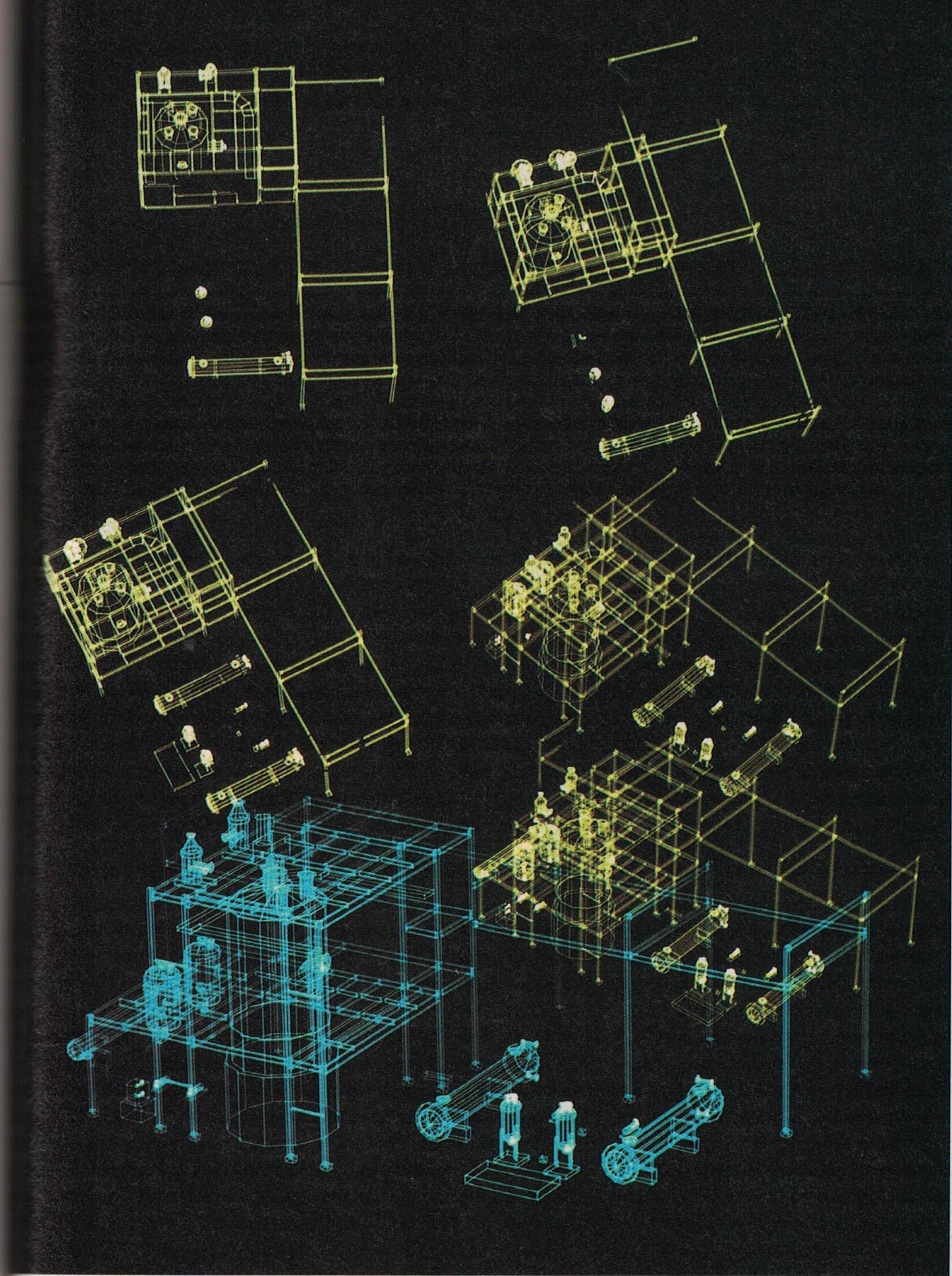
Saying it with pictures

The CAD of CAD/CAM is basically designing, drafting, and analyzing with computer graphics displayed on a screen. "Everything a draftsman needs is in the computer," says Ronald A. Cenowa, a computer engineer in GM's Fisher Body division in Warren, Michigan. "Anything that a draftsman conventionally does using triangles, pencils, compasses, and so on will be done mathematically within this system." CAD not only speeds up the slow and laborious work of drafting, but also enables the designer to study various aspects of an object or assemblage by rotating it on the computer screen, separating it into segments, or enlarging or shrinking details.

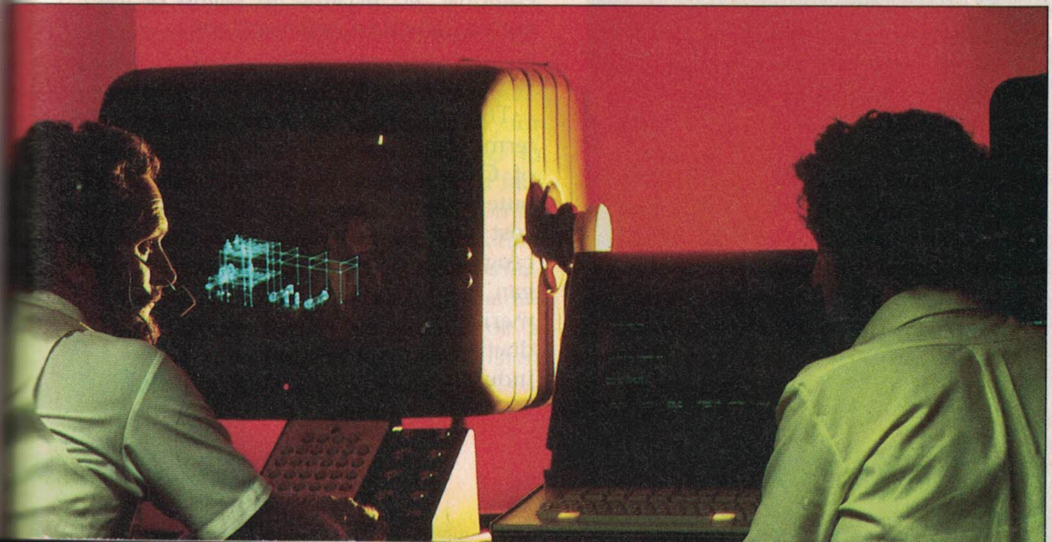
What makes CAD so effective a way to design and analyze products and components is that the computer communicates with the designer in pictures. The mind absorbs the information content of a displayed diagram or drawing much faster than it can take in an array of numbers or words and mentally translate them into images. "Computer graphics," a scientist says, "seems to tap the way the brain is designed to work."

What's more, if the necessary programming has been done, the designer can analyze and test the things he designs right in front of his eyes, subjecting them to electronically simulated temperature changes, mechanical stresses, and other conditions that might impinge in real life. This on-screen testing can save the huge amount of time and expense involved in fabricating prototypes, then testing, modifying, and retesting. Donald D. Parker, a Fisher Body engineering executive, says in praise of CAD: "We do the design work on graphics and look at the results on graphics—all totally devoid of real parts to test. We can go through the whole process and have a good idea what the part is going to weigh, how strong it will be, how stiff, how well it will perform. We fix parts before the car is built."

Behind the visible magic of CAD lies a hidden base of programming. The power to design without setting pencil to paper



Harry Seawell



A Factory in Motion

Use of CAD—computer-aided design—enables Du Pont engineers to view a model of a chemical-processing plant in three dimensions. The views can easily be rotated on the screen for quick checking of how well parts fit together. Du Pont expects use of the new system to cut design time to one-fifth of what was required before CAD came along.

and to analyze and test objects before they exist in the tangible world is created by vast, painstakingly put-together computer programs, often consisting of millions of lines of coded instructions. Battalions of programmers have labored to give the draftsman and the designer, at the press of a keyboard button or the flick of a light pen, the thousands of basic lines and splines (curves), the immense fund of underlying calculations.

Easier changing in midstream

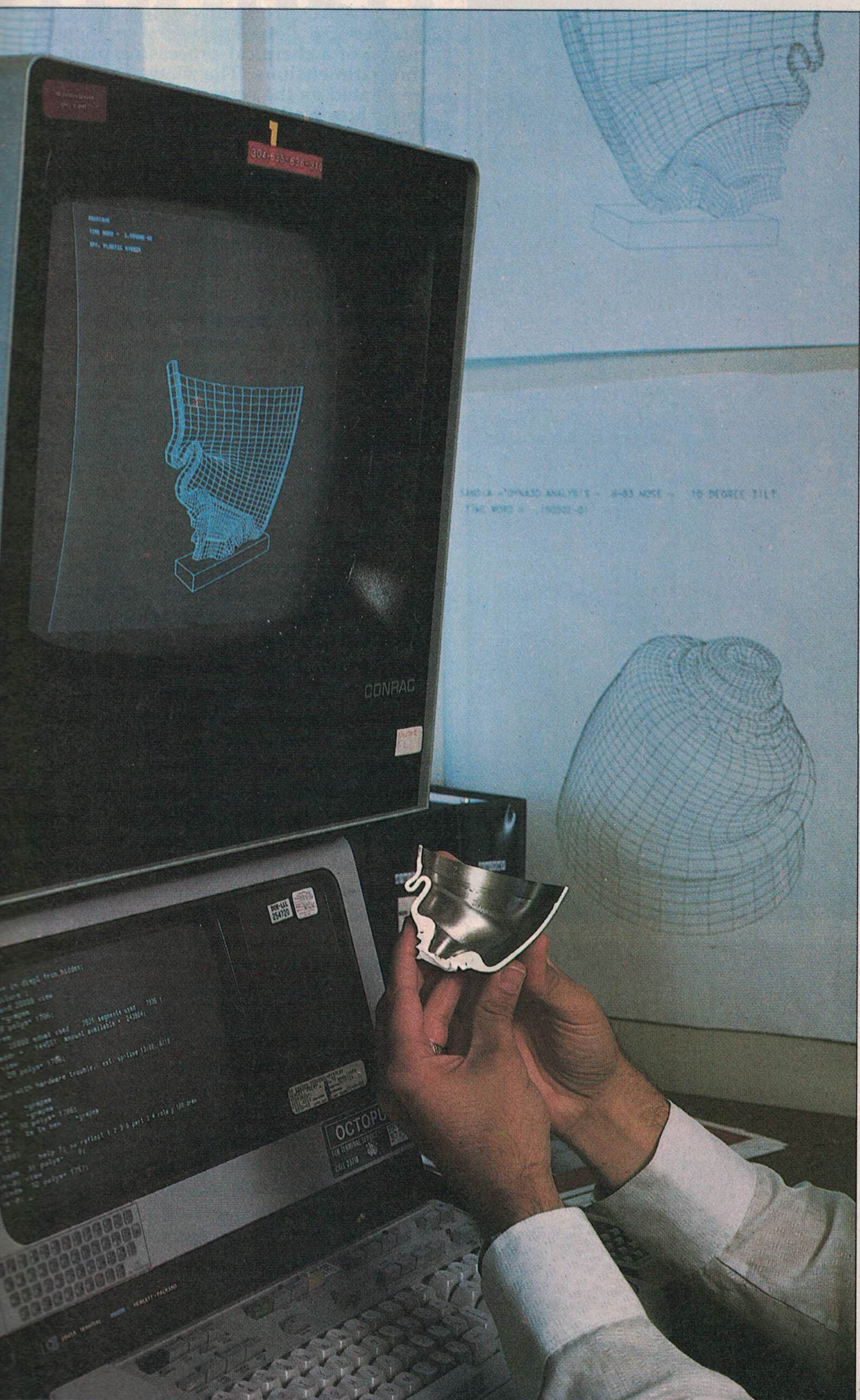
CAM, the other side of CAD/CAM, refers to something that has come to be commonplace in manufacturing plants—computer control of production machines. They range from machine tools running on punched-tape instructions to robots that can be reprogrammed to perform any of a variety of industrial tasks. CAM pays off aside from any connection with CAD, providing speed, accuracy, tirelessness, and dependability that human operators cannot match. But the potentialities are greatly magnified when CAD and CAM are joined together.

When the linkage works smoothly, the on-screen designing and testing of a product generate a bank of computer instructions for manufacturing it—or making the tools, dies, and molds used in manufacturing it. Even the tool paths, visible on the screen, can be specified. This CAD/CAM linkage greatly shortens the time between design and production. It is less costly to move to new models, make midstream design changes, customize products, set up short production runs.

Pratt & Whitney Aircraft, one of the companies that have gone furthest in applying CAD/CAM to manufacturing,

How a Nose Cone Crumples

The accuracy of computer modeling is evident in this simulation of how a nuclear bomb's nose cone will crumple on impact. The nose-cone model on the screen at Lawrence Livermore Laboratory is made up of more than 6,000 individual segments, which a computer analyzes for impact stresses. The one-third-scale model in a researcher's hands is made of metal and was actually put through an impact test. Both versions buckled the same way.



Edward Miller

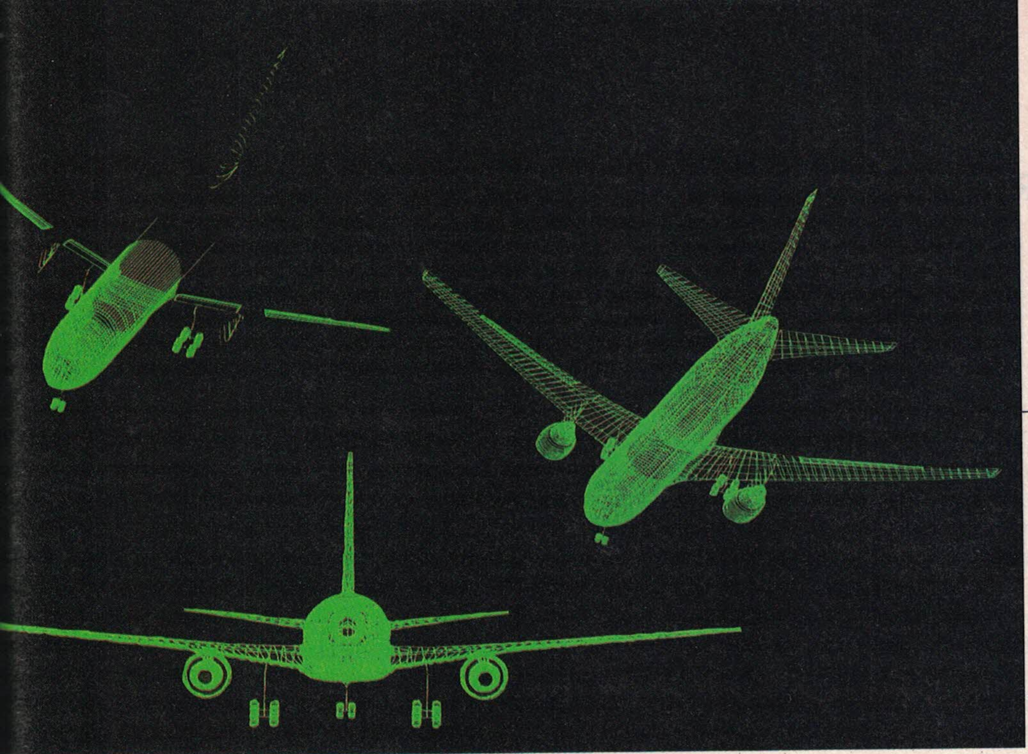
now makes turbine blades, among other things, directly from CAD drawings, with the whole process automated. Edwin N. Nilson, manager of technical and management data systems and scientific analysis, says that in many cases "thanks to CAD we have gained a 5-to-1 or 6-to-1 reduction in labor and at least a 2-to-1 reduction in lead time. And these ratios go up as high as 30 to 1 and 50 to 1 where we linked CAD with CAM."

Someday, enthusiasts predict, CAD/CAM will make manufacturing into a process as smooth and as easily supervised as the flow of liquids in computer-controlled oil and chemical refineries is today. The march toward that goal began in the mid-1950s, when computers started to appear on factory floors in force to supervise the then-new numerically controlled machines. Developed under the sponsorship of the U.S. Air Force, such machines have since spread around the world.

In the beginning, numerical control referred mainly to the use of punched-paper tapes to guide metal-milling machines, but since then the concept has expanded to include many other varieties of machine tools, some of which are now directly controlled by computers without the use of tape. In flexibility, NC machines stand between fixed automation, exemplified by the presses that turn out automobile engine blocks, and the more adaptable industrial robots, which can replace human workers in forging, casting, painting, and even simple assembly operations. NC became an island of automation, albeit an important one.

Toward the ultimate vision

Then, in the early 1960s, the graphics terminals began to emerge—the dawning of CAD. With the spread of minicomputers and the continued decline in the cost of information processing, CAD caught on. Manufacturing engineers began to link computer graphics with numerically controlled machines. The production of hydraulic tubes in the aircraft industry is just one example of that link.



Doug Wilson

A Plane Made of Math

Boeing's new jet transport, the 767, was largely designed through use of mathematical representations inside a computer. Parts and assemblages displayed on the screen could be fitted, analyzed, and subjected to simulated stresses before they existed in tangible form. That saved time and improved design as well.

NC machines driven directly by CAD also shape tools, fashion parts, and cut materials with laser beams.

CAD linked to NC is what CAD/CAM mainly means today in its popular definition. That's an important link. But CAD/CAM theoreticians want to extend the concepts much further, moving toward the ultimate CAD/CAM vision, the automated factory. That involves not just connecting CAD terminals to computer-controlled machines, but thoroughly computerizing a plant's or company's manufacturing operations, including control of the flow of parts and materials and the movement of products through the various stages of manufacture. There's plenty of room for improvement in factory efficiency. Studies indicate that in standard manufacturing a part spends about 5% of the time being machined and 95% moving or waiting.

A reservoir of wisdom

Sometimes the label CAD/CAM implies full computerization, but the term has no precise and settled content—it means different things to different users. Accordingly, some experts in industrial computerization use the acronym CIM, for Computer Integrated Manufacturing, to refer to the concept of the automated factory. As the prophets of CIM envision it, movement toward full computerization creates a common reservoir of computer-stored wisdom regarding all the manufacturing processes of a factory or a division, or even of a big multidivision company.

In an ideal CAD/CAM setting, many people in the factory should be able to tap the common pool of data. Production planners and schedulers, accountants, and shop-floor foremen, among others, should all be able to plug easily into that store of manufacturing wisdom. The creation of such a common data base is the backbone of any system of computer-integrated manufacturing.

The achievement of something like full computerization entails thoroughgoing analysis of manufacturing operations—and perhaps restructuring of them—in order to translate them into precise computer language. This is a demanding and time-consuming task, and few companies are very far along with it. Even the best practitioners of CAD/CAM—certain makers of electronic components, aircraft, autos, farm machinery, and machine tools—employ only a few of the building blocks of a complete CIM system, and for the most part as disconnected blocks. Factory operations may seem orderly enough until you try to describe them in computer programs, but then they begin to look quite irregular.

Full computerization would embrace control methods that have been formulated in recent years. One is the curiously named "group technology," a means of coding and grouping parts on the basis of similarities in function or structure or in the ways they are produced. Application of group technology can enable a company to reduce the number of parts in use and to make the production of parts and their movement in the plant more efficient. Another key discipline is process planning, which details the sequence of steps needed in the making of a part or product.

While some forward-looking companies make use of such disciplines, many others still don't. Computer-integrated manufacturing seeks to computerize these instruction sets, as well as other manufacturing controls such as the planning of requirements for materials, tying them all together into a kind of computer superbrain that will run the factory.

Two organizations have been primarily responsible for focusing the attention of manufacturers on CAD/CAM. The names sound like mirror images: CAM-I (Computer Aided Manufacturing International Inc.), a private group, and ICAM (Integrated Computer Aided Manufacturing), funded by the Air Force.

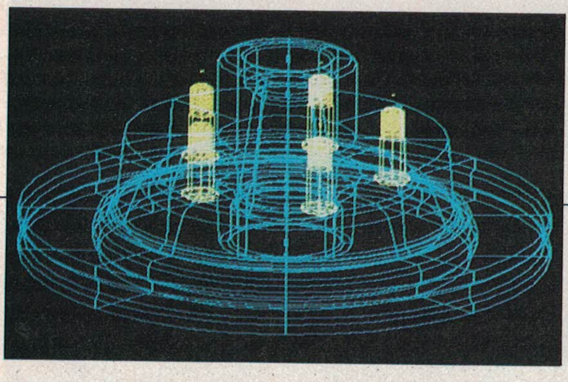
Both emphasize integration. "We want to demonstrate," says ICAM manager Nathan G. Tupper, "that the power of integrating all the pieces is so much greater than the total of all the little bits and pieces. When you consider that 60% to 70% of the cost of manufacturing has got nothing to do with the physical making of a part, but has to do, in fact, with the planning, scheduling, and control of the equipment that makes the part and of the people who operate it, then it seems clear to me that that's where your emphasis should be. If you can build up a common information base, and operate off that with intelligently constructed planning, scheduling, and control systems to drive your automated machinery, or provide instructions to your manually operated machinery, the payoffs are hard to imagine."

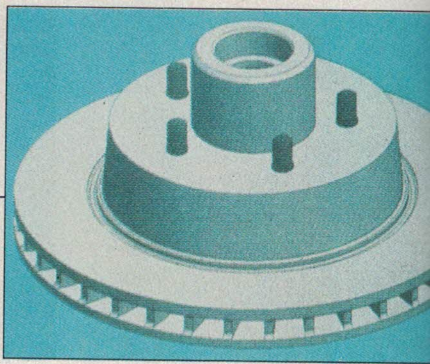
Tougher than getting to the moon

There are obstacles, however, and some will be difficult to chip away. A major one is the lack of uniformity in procedures from one plant to another, or even from one technician to another in a given plant. Process planning, to cite one key activity, is still done largely by hand

Making Computer Models as Real as Life

Computer modeling is now able to construct three-dimensional designs whose interior detail can be displayed on terminal screens, like this model of an automobile disk-brake rotor, produced by an Applicon Inc. program. The rotor can be dissected on the screen.





by individuals of varying experience; each one writes the plan to make a particular part somewhat differently. Another obstacle is the great diversity of incompatible computer software and hardware now in use in most corporations. One of the principal theoreticians of CAD/CAM, Dennis E. Wisnosky, who now directs the CAD/CAM effort at International Harvester, sees the integration task ahead as being maybe even tougher than sending men to the moon.

Among other things, the task will involve undoing the past. "In a valiant effort to get the job done," says Wisnosky, "manufacturing engineers continuously added complexity and controls. Then they divided the problem into small pieces, over and over again. As a result, many factories in many American industries are so complex that they appear to be unmanageable, labor forces seem to be out of control, and costs are all but unknown." In time, he adds, the development of computer-integrated manufacturing will cure those ills.

Wisnosky is putting his ideas into practice at International Harvester, where he has assembled a large group of specialists. Currently beset by financial troubles, the company sees computer-integrated manufacturing as a lever that will help it vault back to the top of its field. Wisnosky and his colleagues work with rotating groups of manufacturing engineers. They began with the idea of devising an architecture, or highly detailed plan, for CAD/CAM. The purpose is to fully describe, in programmable terms, the functions of manufacturing and the dynamic interaction of all the subsystems.

"The recognition that we can attach everything to everything else is somewhat overwhelming," says Margaret A. Eastwood, manager of CAD/CAM architecture and simulation at International Harvester. "And I think that's why you see it only being implemented in little clumps—because it's very difficult to keep it all straight. But it's exciting."

Wisnosky and his team model and test planned modifications in International Harvester factories prior to any major investments in facilities or changes in computer software. The aim is to eliminate unpleasant surprises in putting computer-integrated manufacturing into place.

This is CAD/CAM modeling on a grand scale. It not only examines materials, tooling, equipment, and part geometry for each process, but also seeks the most economical way to do the job. "Our objective," says Wisnosky, "is to match the best process with the best material at the best time."

The hot-sheet evidence

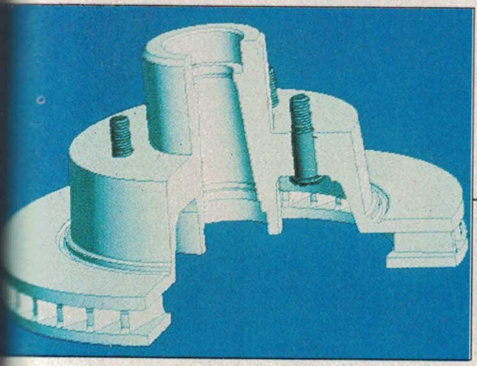
The integration, in effect, seeks to devise a computer-aided scheduling system in which computer controls would respond and react to changes on the factory floor to keep that schedule running smoothly. "There is no system today that can handle this on the factory floor," says Wisnosky. "In every plant in the country you see foremen running with hot sheets in their hands—a list of parts that are needed immediately on the assembly line. Some plants have more expediters than people making things. That's where the tremendous impact of CAM will be in the future—that whole area has not been tapped."

Fortunately, a company need not wait for the full development of CAD/CAM potentialities. As a growing number of corporations are discovering, the available elements of CAD/CAM can already start paying impressive dividends in increased production, in time and money saved, in better-quality products, and in greater flexibility in manufacturing. GM, for example, turns out car-body components such as fenders in half the time it took with manual techniques. What's more, the shapes and dimensions of components produced the new way are more accurate.

Even CAD by itself is a phenomenally powerful technology. At Fisher Body, for instance, a car made of electronic mesh looks like a blueprint in motion as it bumps along a rough, computer-simulated road on a terminal screen. The car's body undulates in a purposely exaggerated fashion when it hits a make-believe bump so that engineers can spot design flaws before prototypes are built. In a similar type of test at International Harvester's engineering-design center in Hinsdale, Illinois, an electronic image of a combine, showing how it would contend with bad weather conditions on the farm, spits out columns of indicator numbers as it strains to extract its wheels from simulated mud on one side while it slithers over simulated ice on the other.

If he is not fully satisfied with his initial creations, the designer can try many variants, taking chances with computer data that he would never take with an actual product. Thanks to this ability to improve products quickly even as they are being designed, says a CAD/CAM executive at General Electric, "a whole new era of producibility" is beginning.

Being able to try out an almost infinite variety of materials, product configurations, and other factors in manufacturing products before committing actual resources can bring large gains in efficiency and substantial reductions in costs. Roland W. Schmitt, vice president for research at GE, reports that savings just from eliminating mistakes in the making of metal molds for plastic parts—GE produces more than 130 million pounds of plastic parts a year—will soon amount to $100 million a year. Images on a terminal screen can simulate the cooling of a



plastic part inside a mold, for example. If the simulated part cools unevenly, a designer can readily see the unevenness, indicated by colors.

Even more capable CAD is on the way as the new computer-graphics technology emerges. Miraculous as today's CAD may seem, it has certain shortcomings. The images usually consist of a network of lines that looks something like wire mesh. That type of structural representation mathematically describes the outlines of the object. Such basic properties of solid objects as volume and center of gravity, for instance, cannot easily be calculated. In wire-mesh images, moreover, interaction between complex parts is sometimes difficult to discern.

The intangible clay

An ideal CAD technology should produce more realistic representations of solid objects. The new three-dimensional modeling does that, and it will drive computer-integrated manufacturing forward on a broad front. Besides making design and analysis of complex parts much easier, it will provide vital information to everyone in the factory with greater clarity and precision than is possible with wire-mesh modeling. A process planner, for instance, should have a clear, three-dimensional conception in his mind not only of the completed part but also of the changing shape of a block of metal being worked on as it proceeds through the machining process. Solid modeling can give him that as a motion-picture-like sequence of images.

With solid modeling, computer programs can represent internal structures as well as external shapes. A designer can construct representations of complex parts the same way a craftsman would make a model of clay, except that now the clay is information stored in the computer. When the electronic solids are cut apart on the screen, all the details one would find inside a real part are clearly visible—a boon to product designers and engineers.

What this means is that design and analysis of complex parts and tools will become much easier than with wire-frame graphics. Later on, they will be manufactured directly from designs. That will represent a considerable expansion of CAD/CAM capabilities, which heretofore have been pretty much limited to objects with rather simple internal structure.

Little wonder that knowledgeable people view solid modeling as the most important single development for the future of CAD/CAM. Norway, which hopes to use CAD/CAM to free workers from the need to toil on third shifts, has traded millions of dollars' worth of natural gas as part of the price of participating with West Germany in a $30-million CAD/CAM program in which solid modeling plays a central part.

Solid-modeling systems are just beginning to be commercially available. A system from Applicon Inc. of Burlington, Massachusetts—really a complex computer program—sells for $50,000. Other solid-modeling programs are being developed; perhaps the most sophisticated one is being worked out at GM's research labs for in-house use.

Seeing the flame perform

Applying programs developed in collaboration with the University of Rochester, GM technicians found they could use solid modeling to design a car trunk so as to get the most storage capacity. This seemingly simple chore had in fact been pesky and time-consuming; it required the building of full-size wooden mock-ups. GM researchers have also ap-

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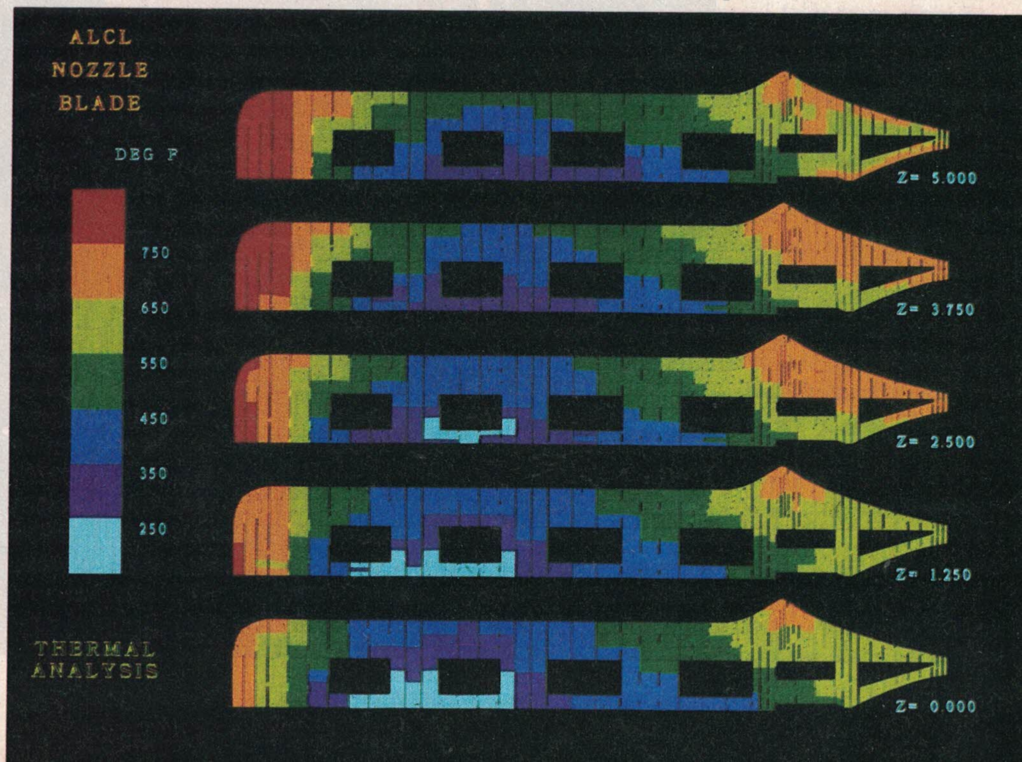
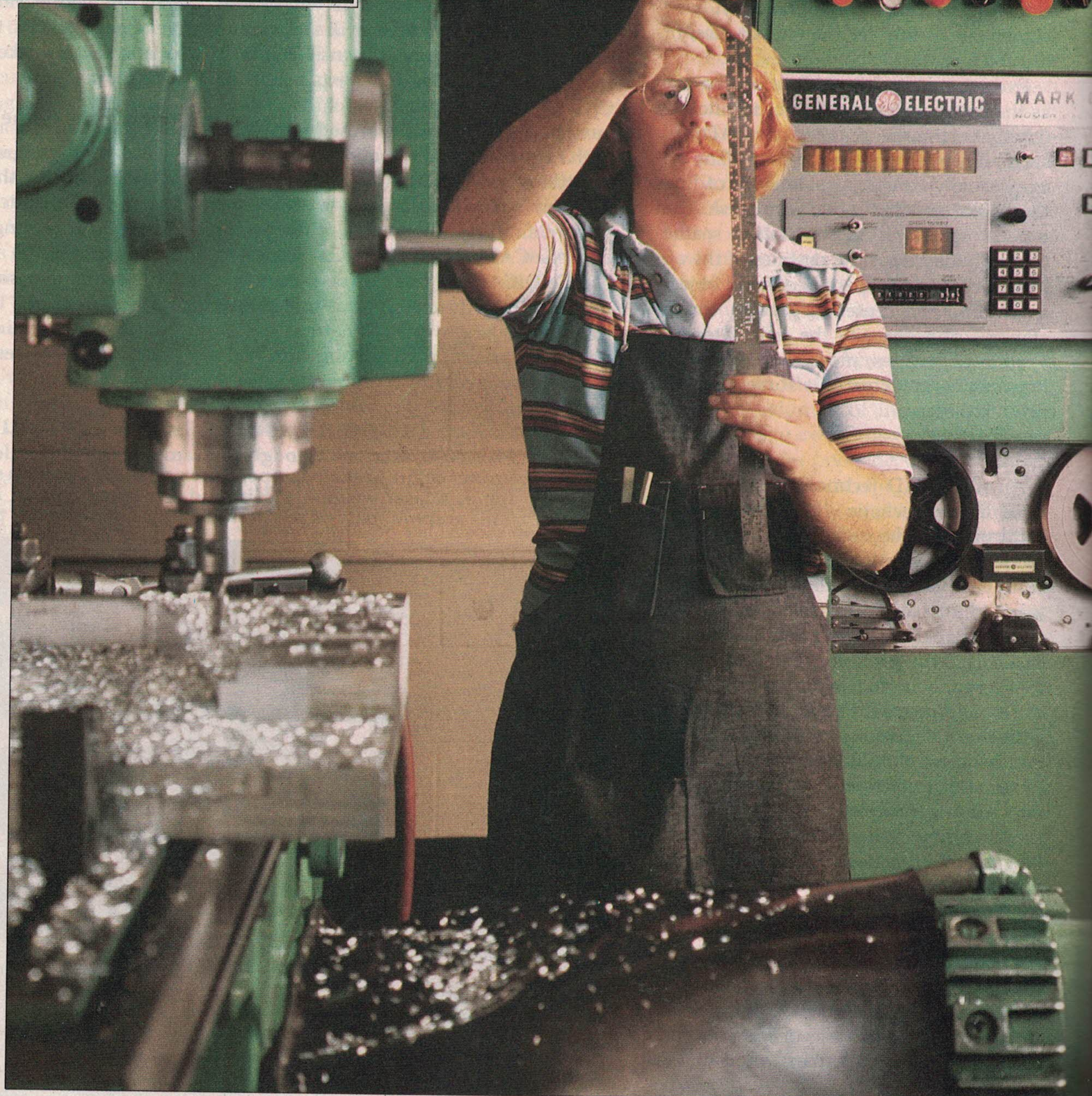
Firing a Laser Inside a Computer

Five cross sections through the same laser nozzle glow in a rainbow of colors to show temperature variations during a simulated firing of a laser weapon at Kirtland Air Force Base in New Mexico. This graphic analysis replaces 300 pages of computer printout.




GENERAL ELECTRIC
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Turning an Image into a Product

Ronningen Research & Development Co., a maker of prototypes for various manufacturers, runs by CAD/CAM. A designer, left, creates a modification of the computer terminal at his side. He then designs injection molds in which the parts of the prototype will be cast. The computer generates the paths of the tools that will cut the molds. An operator feeds the punched-tape instructions into a machine that sculpts a mold from a block of aluminum. Below, another workman lifts a finished plastic panel from the mold.

plied their solid-modeling system experimentally to such complex problems as measuring the moving flame inside a simulated auto-engine combustion chamber—very much akin to looking inside a working engine. What's more, the system makes it easy to vary the chamber design and study the effect of such changes on the combustion process.

A multitude of commercial packages combining hardware with software and offering some unified CAD/CAM capabilities are available today from such vendors as Applicon, Computervision, Calma, and others. (General Electric acquired Calma last year; Schlumberger just announced it's on the way to acquiring Applicon.) Prices range from about $150,000 to $800,000 and more. The CAD/CAM vendors may constitute the fastest-growing industry around (see Personal Investing, September 8, 1980). It is expected to hit $750 million in sales this year and $2.2 billion by 1984. It is Wall Street's latest darling, and P/E ratios reflect infatuation.

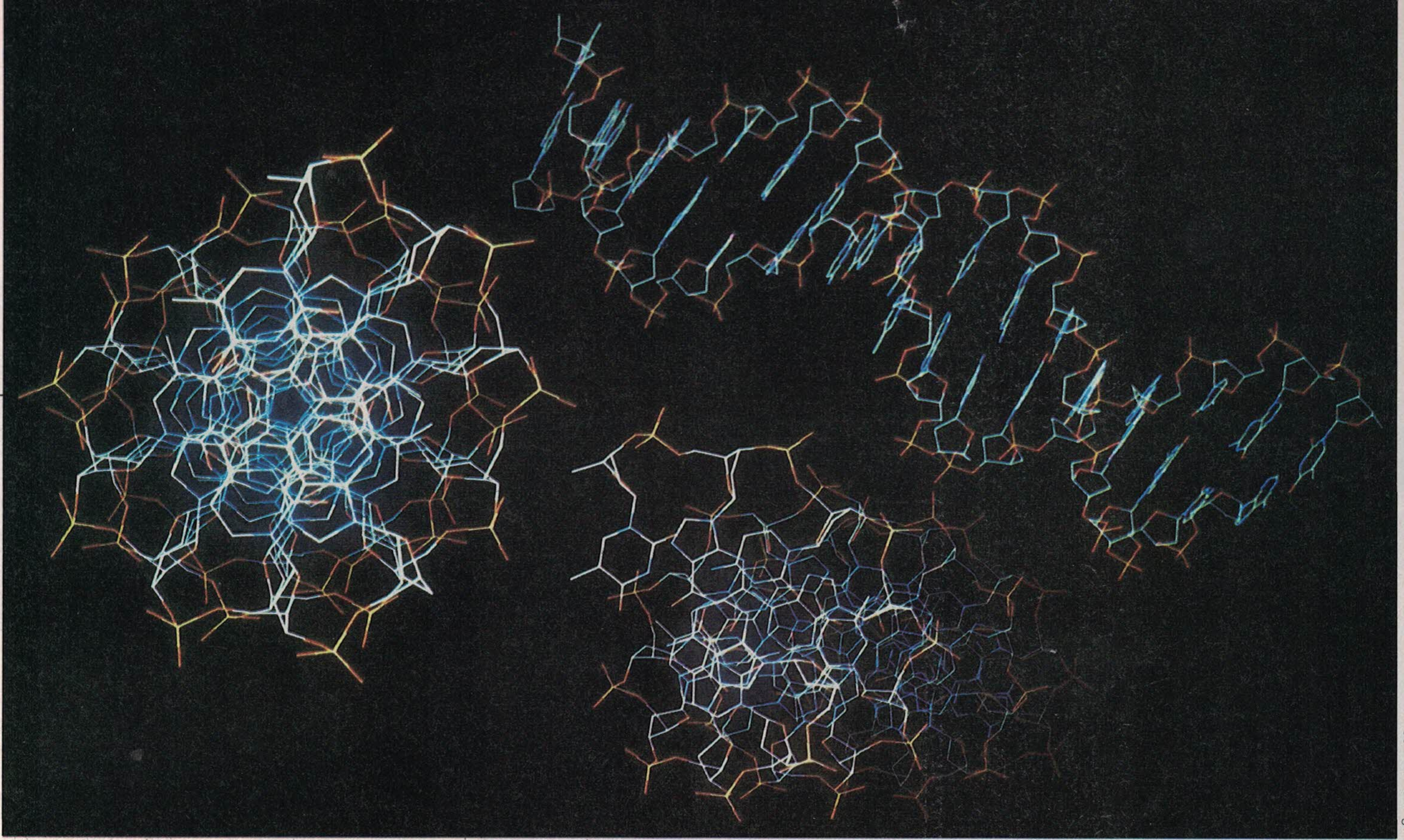
Using the CAD/CAM packages, which usually pay for themselves within a year or so, can bring pleasant rewards. One happy customer is Robert M. Ronningen, president of Ronningen Research & Development Co. of Vicksburg, Michigan. His company makes a wide variety of plastic molds, parts, and prototypes for manufacturers of various products, from steering wheels to computer terminals. A little over three years ago, it installed a Unigraphics minicomputer-based CAD/CAM system, marketed by McDonnell Douglas Automation Co., a subsidiary of the aircraft maker. Since then Ronningen Research has more than tripled in size, from 30 employees to 100.

"I still get kind of amazed"

A mechanical engineer who says that he is "always looking for a better way to build a mousetrap," Bob Ronningen credits his CAD/CAM system with lifting his company to the forefront of prototype manufacturers. "I still get kind of amazed how fast we can do things now," he says. "We can build an injection mold in two to three weeks with Unigraphics. Without it, the same work would take from eight to 16 weeks."

At Ronningen Research, CAD/CAM takes a product from design to manufacture under computer control (see illustrations). The merger between CAD and CAM is much more difficult to execute on a large-factory scale, but more and more corporations are trying. Some, notably in aerospace, have already carried the integration a long way. McDonnell Douglas, one of the pioneers, has devised a common data pool that is directly accessible to the aircraft-structure analysts, the design engineers, the numerical-control programmers, and the parts inspectors. The output in the form of CAD drawings or numerical instructions speeds along special communication links to automatic drafting machines, metal-milling tools, and inspection devices. Control programs monitor and direct all these busy pieces of apparatus. A management data-acquisi-

Wayne Sorce



John A. Reminger

Designing Drugs Without Chemicals

Drug design is moving from the lab to the terminal screen. At Merck Sharp & Dohme, a computer-generated portion of the DNA molecule is rotated for viewing from three different angles. Being at the core of life, DNA is of special interest to drug researchers, who study how new drugs interact with it. They design drugs and check out their properties without leaving the consoles.

tion system watches over the status of all machine tools, and frequent status reports inform shop managers about the number of completed units, unit cost, and operator productivity. McDonnell makes about 85% of a fighter plane by automatic means. Yet an executive concedes that even McDonnell has not yet reached the CAD/CAM "destination."

Reaching that destination will entail the further step of computerizing the factory-control functions. Lockheed Georgia Co. is getting there. It took a program for computerized process planning, developed by CAM-I, and improved on it to a point where a process planner now can write 50 to 100 simple production plans a day, compared with the three or four he used to do manually. But to get that logic into the computer, Lockheed Georgia grilled the best of its manufacturing people for seven months. This is another piece of evidence that to reap the full benefits of computerization, manufacturers have to look very deeply and painstakingly at their operations in order to understand them well enough to make them understandable to computers.

Smaller companies will have to rely on programs they can obtain from vendors, and there's plenty more help on the way. Some big guns are moving into the CAD/CAM marketplace. General Electric has made a $500-million commitment to become a "world supermarket of industrial automation" in the 1980s. Senior Vice President Donald K. Grierson has promised that GE's systems will be able "to blast productivity through the roof."

To be with it at the club

IBM, which for some years has been offering a Lockheed-developed CAD/CAM system that runs on IBM computers, is highly interested in factory automation as an expanding market. Both Sperry Univac and Honeywell also have plans to offer big CAD/CAM computer systems that will go beyond the smaller versions offered by Computervision, Applicon, and other independent vendors. The mainframe makers feel that advanced solid modeling in particular will demand huge number-crunching capability.

With big computers or small, CAD/CAM is moving along. In the words of Joseph F. Engelberger, president of Unimation Inc., the leading maker of industrial robots, "the word is out" that CAD/CAM is the wave of the future in manufacturing. "I don't think a guy will be able to go to his country club if he doesn't have a CAD/CAM system in his factory. He's got to be able to talk about his CAD/CAM system as he tees off on the third tee—or he will be embarrassed." He may be worse than embarrassed if CAD/CAM prophets are right that it offers the only means by which the U.S. can survive as a competitive industrial power.

The mystery factor, as usual, has to do with the Japanese. Will they grab a technology that is as American as the space shuttle and run away with it, as they have done with so many other technologies? Right now, the Japanese are lagging in linking CAD with CAM but catching up fast, mainly by buying American technology. They can hardly have failed to hear the refrain that CAD/CAM vendors and technicians seem never to tire of repeating. "CAD/CAM," it runs, "has more potential to increase productivity than any other development since electricity." F