

## PUTTING COMPUTER-AIDED DESIGN TO WORK

APL is using state-of-the-art computer-aided design technology to develop an exciting variety of modern electromechanical systems. Applications include the Cosmic Background Explorer satellite, a paravane underwater towed vehicle, and prototype AEGIS shipboard electronics systems. Proper use of computer-aided design technologies in the laboratory environment can result in extremely well-designed, high-quality, and highly reliable hardware. Capabilities such as three-dimensional geometric modeling and automatic printed circuit board design enable the engineer to solve difficult problems that were done previously by trial and error.

### INTRODUCTION

Hardware development work in support of Fleet, space, and other programs at APL generally falls into two categories. The first, mechanical work, includes complex structures such as spacecraft, underwater vehicles, and intricate mechanisms to manufacture contoured shipboard equipment. The second, electromechanical work, includes dense multilayer printing wiring, stitch bonded or wire wrapped circuit boards plus associated hardware, and cabling for space and shipboard applications.

The Laboratory confronts some interesting challenges in the hardware development process, such as the design and fabrication of one piece of complex hardware that will be used as a prototype and must work the first time it is produced. Examples of how computer-aided design (CAD) has helped in the design process are discussed.

### APL'S HARDWARE ENVIRONMENT

In the development of prototype hardware, each design must be produced with adaptability in mind. The first unit, which in many cases is the only unit built, must be fully functional and highly reliable. Such a hardware development environment allows only a short time for refinement of design and manufacturing techniques. Thus, for most programs to be successful, the hardware design must be able to evolve rapidly to maturity during the fabrication and test processes.

The basic types of hardware being developed at APL have not changed over the years; mechanical structures and electrical circuit boards for Fleet and space applications are still being built. However, the design constraints have become increasingly limiting. In the mechanical domain, the types of materials available have increased, tolerances have narrowed, and the complexity of part shapes has increased. In the electrical domain, the complexity of components as well as the number and types available have caused design detail to grow, principally in the number of interconnections to be implemented for a given area. At the same time, the overall

size of the physical circuit medium has continued to shrink. The result in both cases is a need for greater confidence up front in the design in order to avoid costly and time consuming cut-and-try efforts.

CAD tools can help deal with ever-narrowing design constraints and growing design database requirements. The CAD industry has been in existence for about 15 years and now offers a wide range of design capabilities. Many CAD tools, such as three-dimensional (3-D) geometric modeling and automatic circuit board design, were designed to help cope with continually more complex design problems. The CAD techniques that are particularly applicable to the design work at APL are discussed here. For more information about APL CAD software and systems, see the article by West et al. elsewhere in this issue.

### MECHANICAL DESIGN

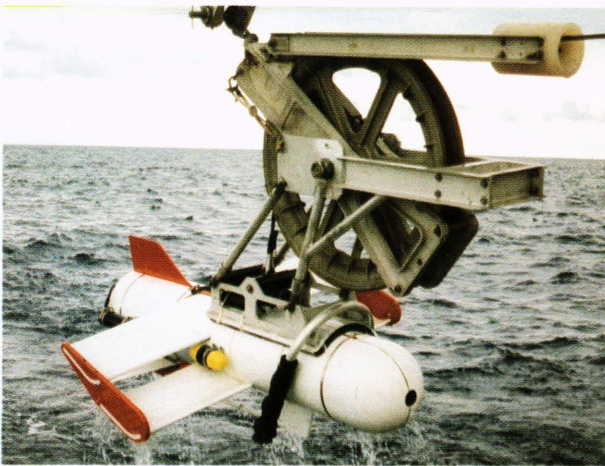
The mechanical design work done at APL includes structural designs such as satellite outer bodies or underwater pressure vessels, various mechanism designs, and specialized electronics housings.

#### Structural Design Example

A primary advantage of CAD for mechanical design is the ability to design in three dimensions. Lines, points, curves, surfaces, and solids can be drawn using x-y-z coordinates; parts and assemblies can be viewed from any selected angle and dynamically rotated about any desired axis for visualization purposes.

The Standard Rampart paravane of APL's Submarine Technology Department is a typical structural design that was developed on the CAD system. Figure 1 shows the designer and the engineer at the Computervision CADD5 4X workstation. Note the use of 3-D and color to visualize the complex assembly. The bottom photograph shows the finished towed vehicle being lowered into the water for use at sea. The CAD system provided the capability to fit-check the individual piece parts and the sensors mounted in the paravane.

In addition to the ability to generate 3-D geometry and drawings, the designer has the power of the engineer-



**Figure 1**—The designer and the engineer viewing the Standard Rampart paravane 3-D layout on the CAD screen. The paravane is an underwater towed vehicle. The finished product is shown in the bottom photograph being lowered into the water for use at sea. Important design considerations were mass properties such as center of buoyancy and assembly fit-checking.

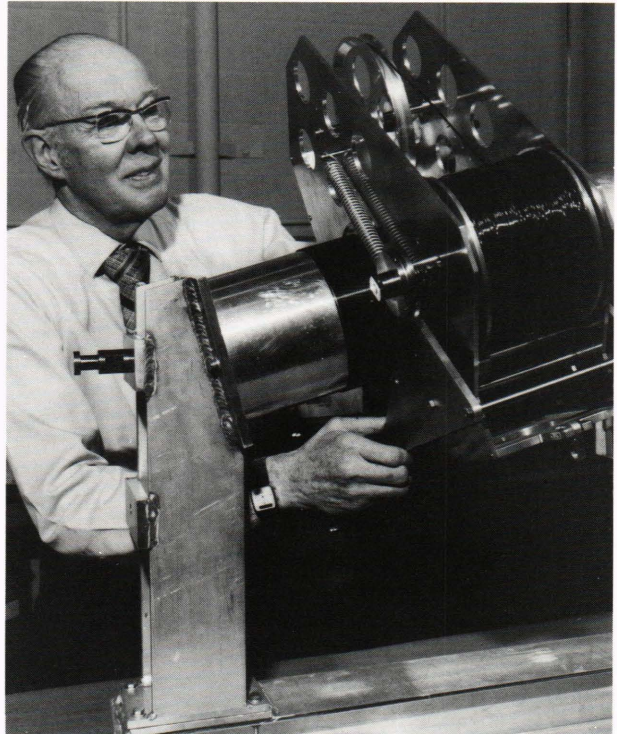
ing database that he has created. From the database, semiautomatic extraction of mass properties such as centers of gravity, moments of inertia, centers of buoyancy, weight, surface area, and others are possible.

Engineering calculations such as center of gravity and center of buoyancy were made for the job in one-half to one-quarter the time taken to do them by hand. Many of the calculations in the complex curved surface areas, which were done on CAD with as high an accuracy as the simple geometries, could only be approximated by hand-calculation methods.

The final result of the layout and engineering effort performed using the CAD system was efficient design development that enabled the fabrication and assembly of the paravane to proceed smoothly.

### Mechanism Design Example

An example of a typical mechanism design is the coil winder built for the Fleet Systems Department; it is shown in Fig. 2 being operated by its design engineer.



**Figure 2**—The AEGIS design engineer tests a coil winder for precise wrapping of a small-gauge wire on the large-diameter curved tube shown. The winder was designed using CAD for accurate layout plus weight and center-of-gravity optimization.

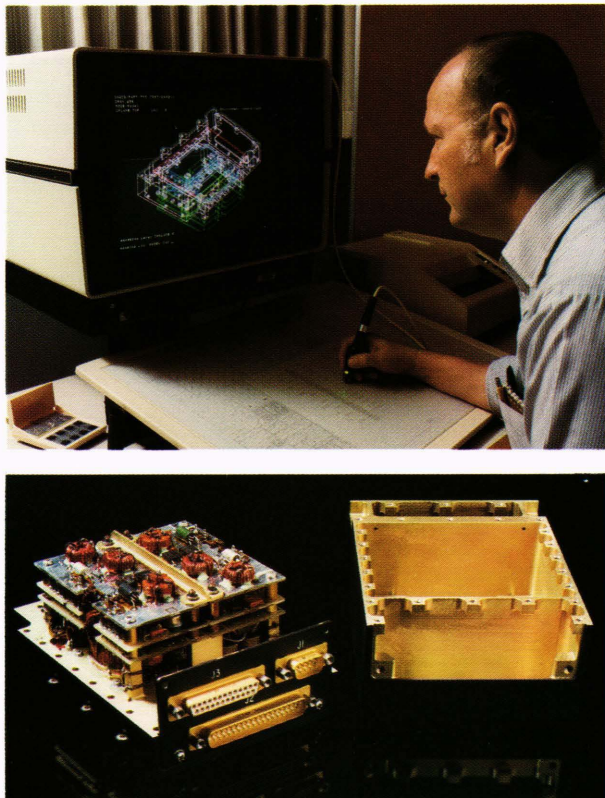
The purpose of the custom-designed winder is to wrap wire precisely around a large-diameter tube that is bent so that its centerline follows a third-degree curve. In order to complete the design, accurate center-of-gravity and weight calculations were required. Basic geometry layout was critical due to the close tolerances involved.

The drafting capabilities of the CAD system were used for the many detailed part drawings required to build the assembly. Once the designer completed the geometry layout, multiple views of the same 3-D object or assembly were easily placed on a single drawing format in the desired orientation. The views were then dimensioned and annotated just as a drafter would do normally, but the system performed the dimensioning calculations automatically at the designer's request.

The result of the design and drafting effort was a design process that was very easy compared to that using manual techniques, and an output of engineering drawings that were efficiently produced and clear in presentation to shop personnel. The result was a simplified fabrication effort.

### Housing Design Example

The dual-precision clock system built for APL's Space Department used electronics enclosed in housings that are typical of those used for flight hardware. Such a housing is shown in Fig. 3. The bottom photograph shows finished housing and associated electronics hardware. The design of housings requires good 3-D visualization while doing the geometry layout in order to place



**Figure 3**—The designer of the dual-precision clock system electronics housing at the Computervision CADD5 4X workstation. Note the use of the CAD system for complex 3-D layout work. The designer uses the pen and tablet to give English-like commands to the computer to draw geometry such as lines, circles, or text. The bottom photograph shows the housing hardware and associated electronics.

the housing pockets and islands in the correct locations and depths. Note the use of 3-D layout and color to help visualize this moderately complex single-part geometry. A common next step in housing design is to insert the circuit board outlines into the housing on the CAD system to check interference between parts. This is normally done in dense packaging applications.

### Manufacturing Database

Manufacturing support can be provided in addition to the design support available by use of the engineering and design database. The numerical control programmer can directly access the design database and use it to define the graphic tool paths that the cutter will follow to machine the part. The cutter location data can then be translated into machine controller language and sent to the factory floor to automatically drive the milling, turning, punching, or cutting machine that will make the part. With this capability in the CAD system, the numerical control programmer has direct access to the most complex curve and surface data, rather than having to interpret that information from a paper drawing.

The housing for the dual-precision clock system was developed using CAD for design and numerical control programming. The use of numerical control fabrication capabilities was very effective on this job, producing the

part in less overall time than do conventional methods, with no scrap or rework required. Conventional methods produced the part in 130 hours. However, a machining error was made, the part was scrapped, and at least 65 additional hours would have been required to make a second part. Numerical control programming plus machining time to produce the part totaled 98 hours, and it was accepted the first time through inspection.

CAD machine tool programming is applicable to most mechanical fabrication work done at APL. It is particularly productive with complex work such as electronics housings that involve milling of pockets containing islands of various shapes and at various depths. Other areas in which productivity is enhanced include curve profiling, surfacing, and designs that require many drilling operations on a single part. For more specifics about CAD/numerical control capabilities and applications, see the article by Hagler elsewhere in this issue.

### Library and Family-of-Parts Concept

One inherent CAD capability is the storage of designs for commonly used parts or even whole systems for later retrieval, modification, and reuse. An extension of that library capability is called the family-of-parts concept, by which the designer can enter common geometric shapes or shape assemblies into a library and then call up the common shape when needed, enter variable parameters, and instruct the system to draw the shape with new size parameters at any location on the drawing.

APL has used the concept since the 1960s for what is referred to as the "Book" and "Half-Book" electronic packages for Space Department work and in other areas. Using CAD, it is possible to also standardize simpler geometries, which can be compiled into complete parts and, further, into complete assemblies; the result can be a much faster, complete design process. The first housings designed and built from a master database family were for the Polar Bear satellite program and were similar to the one shown in Fig. 3. Improved efficiency was achieved for the seven different parts produced when designers used the standard housing for which a CAD design and a numerical control tool-path database existed.

### Mechanical Summary

Activities that benefit from the use of the CAD mechanical capability include layout work requiring 3-D visualization and fit-checks on mating parts, designs with repeating or similar geometry, and designs containing complexities such as spline curves and surfaces. Extremely large or small designs are done with equal ease. Drafting and numerical control programming are expedited when a CAD design database exists from which to begin.

## ELECTROMECHANICAL DESIGN

### APL Electromechanical Hardware

The design of the 5-megahertz dual oscillator for the Space Department is a typical electromechanical hardware development job at APL. Figure 4 shows the oscillator built to a design of the 1970s. Similar units have been used in numerous Space Department programs.



**Figure 4**—The 5-megahertz dual oscillator unit and associated engineering drawings shown represent the typical amount of design information required to build such a common electronics unit at APL.

The basic unit has been configured in many packages but has been only slightly altered in its numerous configurations. The designs of the circuit boards and housing for a unit like this typically involve such design constraints as size (resulting in high circuit board density), weight, structural integrity (stress/pressure), thermal management, and complex housing geometry.

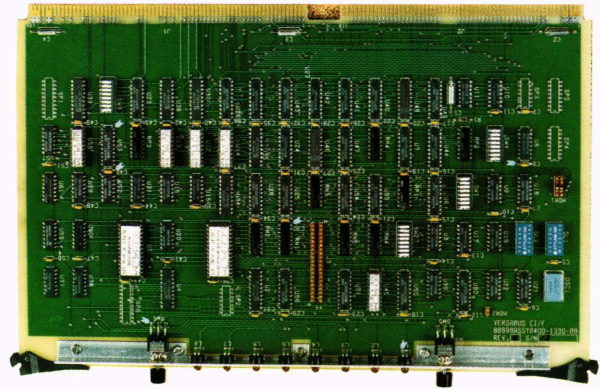
Also shown in Fig. 4 are the drawings needed to fabricate the unit. They represent a paper version of what is referred to in CAD terms as the design database. As can be seen, a large amount of information is necessary to build a unit such as the 5-megahertz dual oscillator. This is a good example of a situation where use of the CAD/numerical control database would expedite the original designs as well as future modifications.

### Multilayer Printed Circuit Board

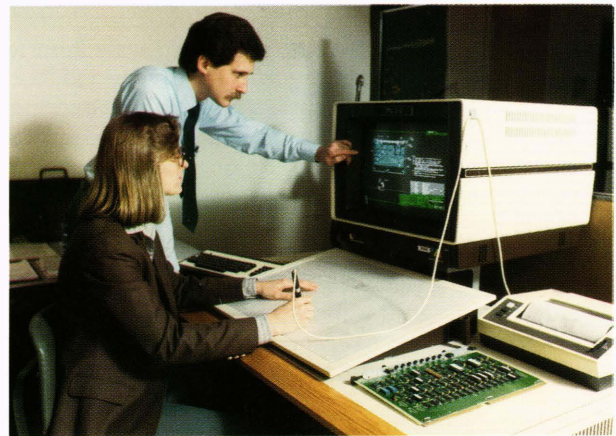
An example of a high-density design requiring the CAD techniques is the SIM/STIM (simulate/stimulate) computer interface board used in the AEGIS program. The board hardware is shown in Fig. 5. The engineer and the designer who are responsible for the design are shown in Fig. 6 at the Computervision CADD5 4X workstation. The board is a six-layer plated-through-hole printed circuit board consisting of four signal layers, one ground layer, and one voltage plane layer.

The CAD system has the advantage of being able to provide the accuracy needed to route 5- to 15-mil fine-line printed circuit traces for this type of dense packaging. Semiautomatic design rule checking allows the CAD designer to perform geometry checks such as pad-to-pad spacing, track-to-track spacing, pad-to-track spacing, open circuits, and short circuits.

The system can automatically place components and route the circuit board track to component pins given a component/pin interconnection netlist extracted from the CAD schematic. This is particularly useful for placement and routing of high-density circuitry where heavy bus-oriented signal interconnections are present. The schematic can be drawn by means of the CAD system,



**Figure 5**—The finished multilayer circuit board assembly of the AEGIS SIM/STIM computer interface. The board is a typical example of CAD application for dense routing. CAD routed 95 percent of the board automatically.



**Figure 6**—The engineer and the CAD designer viewing the circuit board assembly of the AEGIS SIM/STIM computer interface. The board hardware is shown in the foreground. Three such multilayered boards were designed using CAD.

and the netlist can be extracted from the CAD schematic database for use in autoplacement. Also, as is increasingly the trend, the netlist can be read electronically from a computer-aided engineering system and used without drawing a CAD schematic. For more information about electrical CAD/computer-aided engineering software and systems, see the article by West et al. elsewhere in this issue.

The CAD system automatically routed 95 percent of the printed circuit traces (1092 of 1150 terminals) on the AEGIS board. The netlist used was transmitted electronically from a Valid (Valid Logic Systems, Inc.) computer-aided engineering system. The resultant design successfully completed the functional testing phase with no design iterations, which shortened the normally lengthy testing and final development process. The use of CAD automatic routing and design rule checking techniques contributed to this success.

### Stitchweld Example

From the design database described above, the CAD system can produce photoplotted artwork films for use

in etching printed circuit track onto the circuit substrate. The CAD system also generates drilling and periphery routing tapes directly from the electrical design database. The tapes drive the numerical control machine tool that is used to fabricate the board substrate.

Similarly, the system generates point-to-point wiring tapes that drive semiautomatic stitchwelding or wire-wrapping machines. The CAD system can produce other information including test data for an automatic circuit board tester and high-quality detail and assembly drawings used to fabricate, inspect, test, and maintain the design.

Two circuit boards for the Space Department's Cosmic Background Explorer (COBE) program were designed using CAD. One of them is shown assembled in its housing in Fig. 7. The board represents, from an electronic packaging design perspective, one of the more complex design efforts that has been undertaken on CAD in the Engineering Design Group. The design uses a hybrid mix of packaging design technologies including printed circuitry and stitchwelding. In addition to automated fabrication techniques in the drilling and routing area and in semiautomatic stitchwelding, automated testing in the form of numerical control electrical interconnection testing was used along with output from the CAD design database. For more information about electrical fabrication techniques used in the design, see the article by Strider and Wagner elsewhere in this issue.

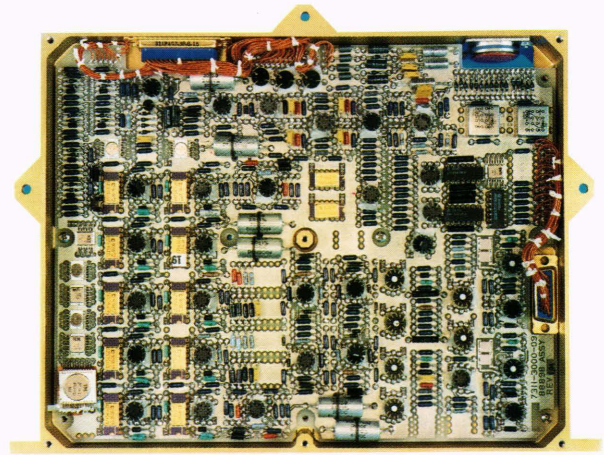
The COBE board described above and its mating board, also designed using CAD, required virtually no design iterations after functional testing, largely due to the CAD design and hardware verification methods used.

### Electrical Summary

CAD electrical capabilities yield the most benefit at APL when used for applications such as high-density, fine-line printed circuit design or heavy bus interconnection logic, and where good quality drawings and schematics are required.

### CONCLUSION

In both the electrical and mechanical examples given, the complexity of the design work was great. As the complexity increases, CAD tools show increasingly greater benefit. In addition, the complete hardware development cycle benefits from the use of a common engineering, design, and fabrication database. Thus, CAD tools



**Figure 7**—The finished COBE circuit board and housing. The board is a very dense dual-layer hybrid that mixes printed circuitry and stitchwelded interconnection technologies. The board was designed on the CAD system, and numerical control machining tapes were provided for housing fabrication.

are not just tools to make drawings faster, but rather tools to develop complex pieces of hardware in even shorter time spans than have been required for less complex designs using manual techniques. Equally important, these designs can be more readily expected to function as desired the first time.

In the future, as more CAD workstations are provided at APL, it will be possible to make broader use of the CAD design database. As more designs are done on the CAD system, CAD drafters and numerical control programmers will be able to use the designs without redrawing the geometry for their own use. As development of CAD hardware continues and faster, cheaper, and better integrated hardware is produced, engineers will have more direct input to and access to output from the CAD system.

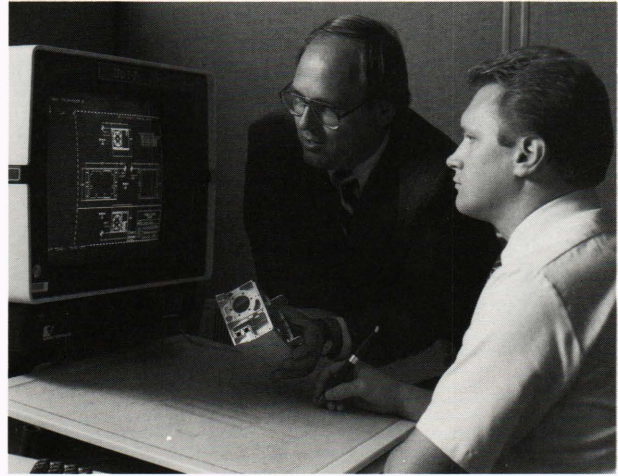
Development in software offered in the future by CAD vendors is expected to include mechanical design enhancements such as refined 3-D solids modeling and faster two-dimensional drafting techniques. Electrical development will include better, faster circuit board routers and software with an improved capability to support advanced electrical manufacturing needs for surface-mounted components and other electrical fabrication technologies.

## THE AUTHORS

STEVEN R. SCHACHTNER (right) was born in Elgin, Ill., in 1956 and completed a B.S. degree in manufacturing technology at Bradley University in 1979. He was employed as a computer-aided design tool engineer by Rockwell International, where he was initially involved in concept design and liaison for assembly and graphite epoxy detail tooling on the space shuttle payload bay doors, the MX missile, and the Boeing 747 and 757 programs and later developed the computer-aided design system for tool design applications.

Mr. Schachtner joined APL in 1983 as an associate engineer assigned to the Technical Services Department's Engineering Design Group. He supervised the Computer-Aided Design Section and has been involved in computer-aided design and computer-aided manufacturing planning, development, and implementation activities. He is now an engineer in the Computer-Aided Design Group, primarily focusing on continuing computer-aided design and computer-aided manufacturing implementation tasks. He is a member of the ANSI committee on Digital Representation for Communication of Product Definition Data.

STEPHEN D. AHLBRAND (left) is supervisor of the Engineering Design Group in APL's Technical Services Department. Born in Columbus, Ind., in 1946, he received his B.S. degree in electrical engineering in 1968 from what is now the Rose Hulman Institute of Technology. He received an M.S. degree in electrical engineering in 1976 from The Johns Hopkins University. He worked at APL in 1967 as a summer student, joining the staff as a full-time employee in 1968. Mr. Ahlbrand has been a hardware design engineer



on numerous APL programs including the Ocean Data Acquisition Program and now develops computer-aided applications. He is a member of the International Electronic Packaging Society and is APL's representative to the Institute for Interconnecting and Packaging Electronic Circuits.