Productivity Improvements Through the Use of CAD/CAM

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This paper focuses on Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) productivity improvements that occurred in the production of commercial aircraft between 1979 and 1983, with a look at future direction. Since the introduction of numerically controlled machinery in the 1950s, a wide range of engineering and manufacturing applications has evolved. The main portion of this paper includes a summarized and illustrated cross section of these applications in the aircraft manufacturing industry, touching on benefits like reduced tooling, shortened flow time, increased accuracy, and reduced labor hours. The current CAD/CAM integration activity, directed toward capitalizing on this productivity in the future, is discussed.

Introduction

IN the manufacturing and engineering environment, thousands of manual tasks have been automated through the use of computers. A look at any process, from layout through assembly, will disclose some computing use. This incorporation of computing tools in portions of the design/build cycle has resulted in reliance on two methods of information handling—manual and computerized (Fig. 1). Each of these methods uses a separate source of data: drawings or data sets. Because both data sources are used interchangeably, the cost of each is retained. Each time a manual method is used in conjunction with an automated one, the flow of information is duplicated. Both the drawing and the digital data have to be maintained in parallel to ensure configuration control of the product, thereby increasing the chance of error. Costs can be reduced within a given group by using the computer; however, the computing tool cannot be fully utilized because of the restraint of manual rules.

The use of CAD/CAM has come a long way since its inception in 1958, when aircraft manufacturers first began using computers to make machine-tooled parts. Figure 2 shows the evolution of CAD/CAM within one such company. With a language called Automatically Programmed Tool (APT), numerically controlled machinery was put to work manufacturing parts on the 727 airplane.

Computer Aided Design (CAD), in its present form, began in 1972, when engineers first used APT to drive a pen for production of a drawing. This is very similar to the way manufacturing uses APT to drive cutters. In 1974 the installation of an interactive computer graphics system greatly reduced the time required for part design. The user could obtain an essentially "instant" response, whether drafting wiring diagrams or manipulating the geometry of a single part or entire assemblies.[1]

In 1976, a CAD/CAM Integrated Information Network (CIIN) provided manufacturing with direct access to engineering computer definitions. Today the communication network includes a geometric data base management system that moves data between different plotting and graphic systems and mainframes.

In 1980 a corporate task force was formed to evaluate technology development and its potential for increasing productivity. Concern stemmed from the decline of productivity in the United States, the skyrocketing cost of energy, and competition in the commercial airplane market. CAD/CAM was identified as one of seven technologies that had great potential for increasing the company's competitive position.

A CAD/CAM integration team was established in 1982 to exploit the full potential of existing CAD/CAM capability. CAD/CAM application development possibilities were separated into two areas: structural/mechanical and electronic. The integration team determined that the major benefits of CAD/CAM would only be realized if the formation and use of digital data were standardized. Existing data set practices were inefficient. Although a significant effort was made to achieve the maximum payoff on new-generation, fuel-efficient jetliners, several obstacles were evident: each of the company's product divisions independently implemented computing in a variety of ways, and nonstandard procedures, systems, and methods evolved. Some were better than others. The integration team studied each division's CAD/CAM applications and selected the most practical way to obtain the highest cost benefit. As each technique was evaluated and approved, it was implemented throughout the company as the standard way of doing business.

This paper describes productivity improvements that have occurred in the current production environment and the steps that are being taken to capture and expand these improvements for other applications.

Engineering Computerized Assembly

To understand the potential benefits CAD/CAM brings to an aircraft manufacturing company, consider the example of computerized assembly, used by engineering for checking interfaces and clearances. This visual assembly eliminates errors and improves the quality of assembled components. In one case in which manufacturing used computer-defined data sets, approximately 54,000 fasteners were located, drilled, and installed with no location errors. Computerized assemblies reduced errors and improved fitup so that estimated labor hours for one assembly were reduced by 72% (see Fig. 3).

Designing Like Parts

With APT-based parametric design computer programs, engineering drawings can be made efficiently and accurately. These programs are ideal for contour-related, look-alike parts such as aircraft ribs, spars, stringers, panels, and body frames (Fig. 4).

Before interactive graphics or batch programs, several designers were required for a single assembly. Each part was released with differences that virtually forced manufacturing to custom-build each assembly. With APT-based programs, the basic geometry of these parts can be created to fit perfectly within a contour. Parameters such as thickness and spacing can be varied, and the output can be displayed for design

Received March 17, 1985; revision received July 22, 1985.

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evaluation. With the external contour providing a base, parametric offsets for skin thickness, chords, and stiffeners allow one engineer to design an entire series of aircraft parts or assemblies.

Analyzing Geometry Earlier

CAD provided a high productivity ratio in defining the leading-edge slat geometry for the 767 airplane (Fig. 5). It also yielded a 10-to-1 productivity ratio in defining the positional cams used in the leading-edge slat control mechanism.

The use of these layouts allowed downstream organizations to finalize more detailed geometry earlier in the design stage, which contributed to a more accurate design and prevented later production fitup problems. The use of interactive computer graphics and general parametric programs made it possible to identify or confirm design errors before part production, which in turn produced more accurate parts and fitup.

Using Standard Patterns

Repetitive standard patterns are used for drafting and annotation symbols such as "bubbles," dimensions, and flagnotes. Once a pattern has been created and has been filed in the standard patterns library, it can be recalled instantly as often as required. This eliminates tedious redrafting and, thus, potential errors. Libraries are particularly useful in producing electrical wiring diagrams, where symbols often occur (Fig. 6). Electrical/electronic engineers can access standard pattern libraries of hundreds of components such as diodes, resistors, transistors, connectors, and circuit breakers. These patterns can be nested to create modules that are easily repeated or modified. The overall process of producing electrical wiring diagrams using interactive computer graphics has established a 2-to-1 productivity return.

Coordinating Design Data

Airplane interiors are customized for each airline, making them ideal candidates for the use of computing tools. By using computers as design tools, as much as 50% of the design labor hours previously expended on the release of 767 interior-system installation drawings was saved. Between 5 and 10 passenger accommodation layouts are developed for each customer, from which 1 arrangement is chosen.

Seat and passenger-service unit groups access the same data source to add information. A user-friendly program provides the data needed for placement of interior systems, many of which are keyed to the passenger seats (Fig. 7). For example, the location of the oxygen mask in relation to seat location is very important. Other computer programs produce seat and passenger-service unit installation drawings.

Designing and Fabricating Hydraulic Tubes

Traditionally, a hardware mockup of the aircraft hydraulic system was required to be certain that all its components fit. With the interactive computer graphics system, the engineer

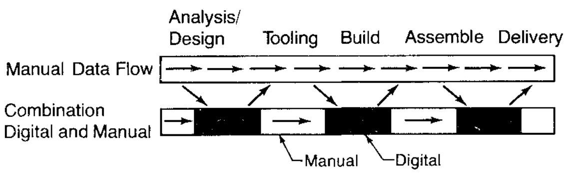

Fig. 1 Manual and digital data flow.

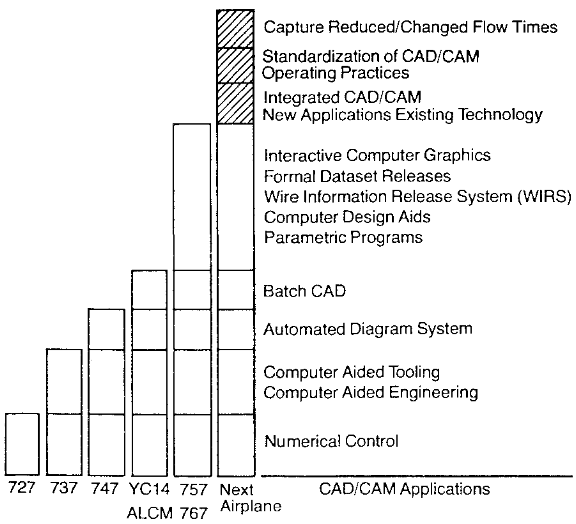

Fig. 2 CAD/CAM applications.

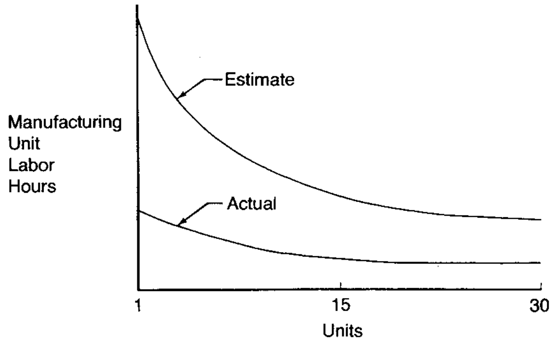

Fig. 3 Wing panel—engineering computerized assembly reduces manufacturing labor hours.

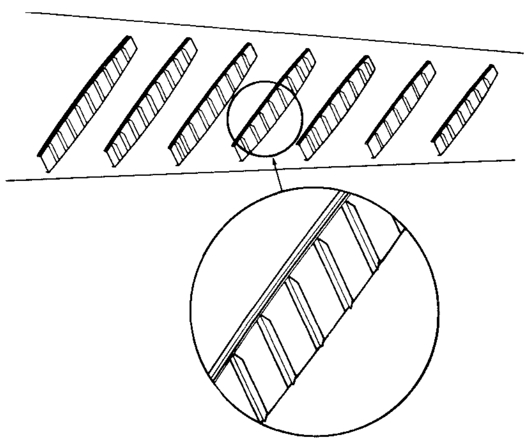

Fig. 4 Inspar ribs—family of contour-related, look alike assemblies.

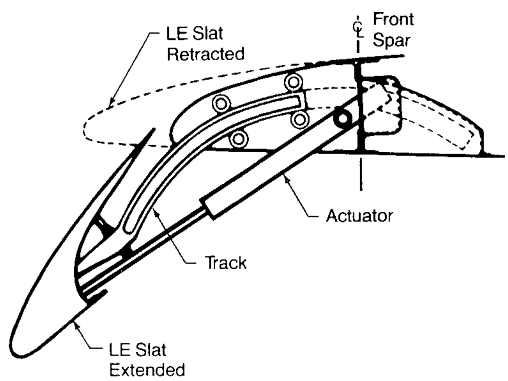

Fig. 5 Leading-edge slat geometry.

can construct a visual computerized assembly of hydraulic tubing and associated structural components (Fig. 8). Analyses are then performed and interferences corrected. Hydraulic tubing designed and manufactured by computers has proved to require less rework than tubing developed by traditional methods.

Engineering geometry also drives Numerical Control (N/C) tube-bending machines. Because the N/C machine is more accurate than manual bending, the scrap rate is significantly reduced. In addition, a representation of the produced tubes can be stored on Mylar, eliminating the need for sample tubes, from which parts can be reproduced.

Making Templates

Templates are used in manufacturing to help make and check parts (Fig. 9). With traditional methods, template making requires a skilled person to shear, saw, drill, file, and deburr the material. With automation, the template maker can obtain needed engineering data directly from a computer data set. Special programs then add manufacturing information to complete the template design. The final template is milled to shape from the design data by numerically controlled machines. With an automated end-to-end process called the Graphics Automated Template System, as many as 1,100 templates per month can be produced. With this system, flow time and labor hours were reduced by as much as 35%.

Drilling Holes

Automated Floor Drilling Equipment (AFDE) is a 400- to 500-pound robot, connected to seat tracks, that drills holes in floor beams, intercostals, and seat tracks on the passenger floor structure (Fig. 10). AFDE is successful because it extracts data from the same data used to machine floor panels and used by quality control to check the parts. Using the same data results in a perfect fit every time. With conventional methods, floor beams are hand-drilled, using templates. Engineering data sets and AFDE have eliminated the need for these templates.

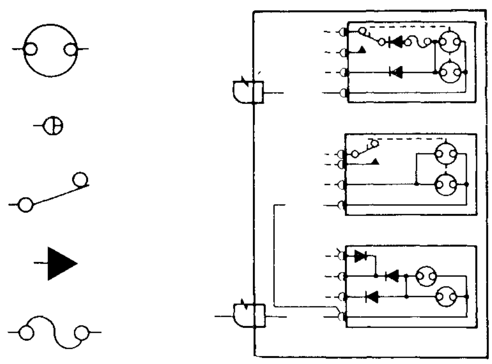

Fig. 6 Electrical wiring diagram symbols.

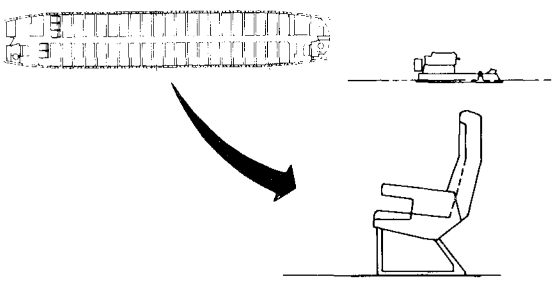

Fig. 7 Seat arrangement with interior systems.

Assembling Wing Spars

Conventional assembly of wing-spar components involved the production and use of templates. Each drilling, reaming, and riveting operation was performed manually.

With the Automated Spar Assembly Tool (ASAT), most of the operations required in wing-spar assembly are performed automatically (Fig.11). ASAT holds the individual spar components together while they are assembled. Hole locations and diameters are specified in data acquired from engineering data sets. At each location the ASAT senses the thickness of the material to be drilled and, in rapid succession, drills a hole of proper diameter, selects a fastener of proper grip length, and inserts it into the hole. Finally, it determines the energy required to insert the rivet or shape the collar. This process is similar to AFDE and will be extended to other flat assemblies, such as in-spar ribs and bulkheads.

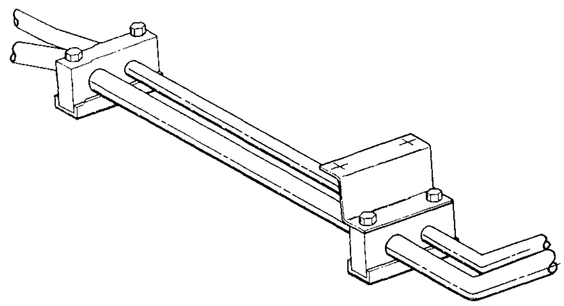

Fig. 8 Tubing and structural components.

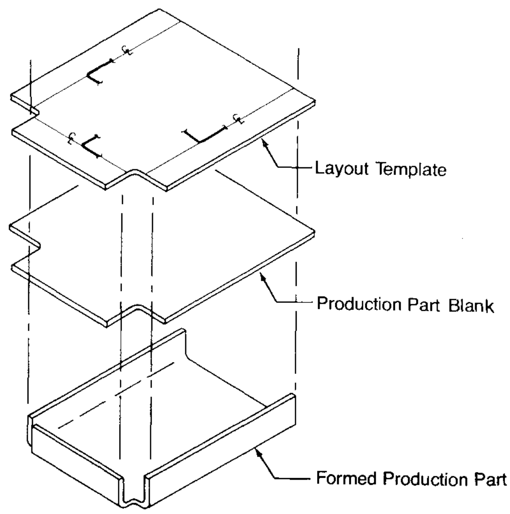

Fig. 9 Layout template.

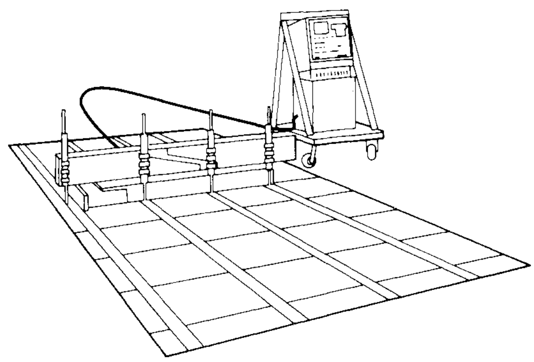

Fig. 10 Automated floor drilling equipment.

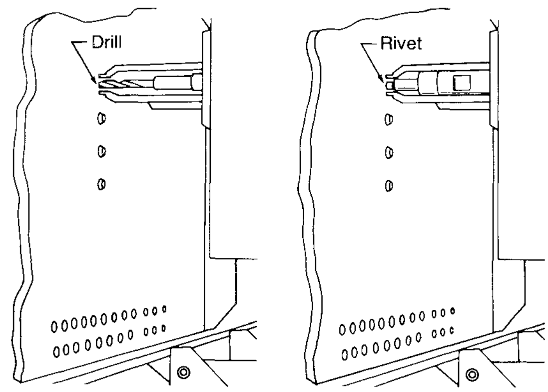

Fig. 11 Wing-spar assembly.

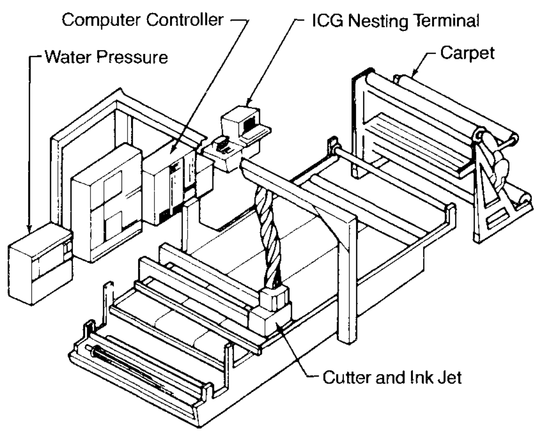

Fig. 12 Computerized carpet-cutting.

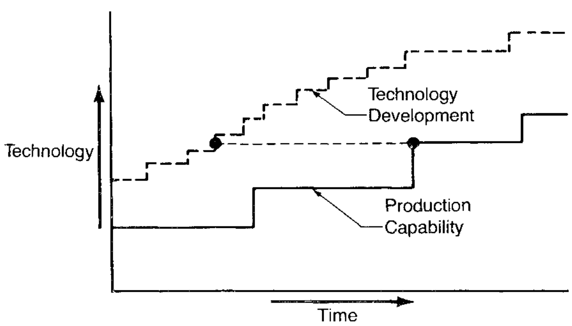

Fig. 13 Development vs production capability.

Carpet-Cutting

Originally, carpet-cutting methods involved designing template tools, laying out the patterns by hand, and cutting the carpet with a carpet knife. The carpet knife left uneven edges that resulted in poor joints, requiring extra rework during installation. Materials and labor hours were wasted. In addition, storage, inventory, and quality control inspection were necessary for these cutting tools.

Numerical Control (N/C) programming produces carpet description files using interactive computer graphics (Fig. 12). Only eight hours are required to produce all the carpet files for an airplane. Template tooling is no longer required, saving tool maintenance costs and an average of 50-80 h per airplane. At a graphics terminal the machine operator can visually arrange carpet images to minimize carpet waste, resulting in a material savings of 10%.

Manufacturing now responds faster to customer and engineering changes. The flow time to incorporate changes was reduced from an 8-h tooling, 10-day lead time to a 1-h programming, 1-day lead time.

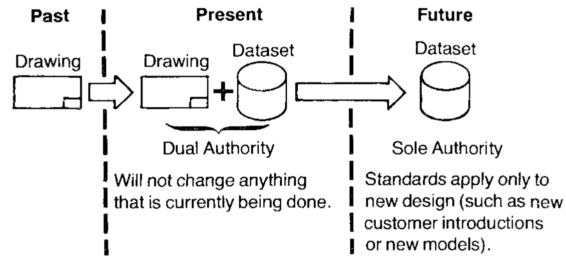

Fig. 14 Past, present, and future data systems.

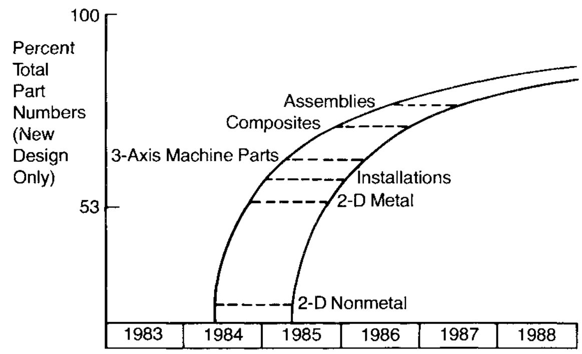

Fig. 15 Planned percentage of parts fabricated using CAD/CAM process.

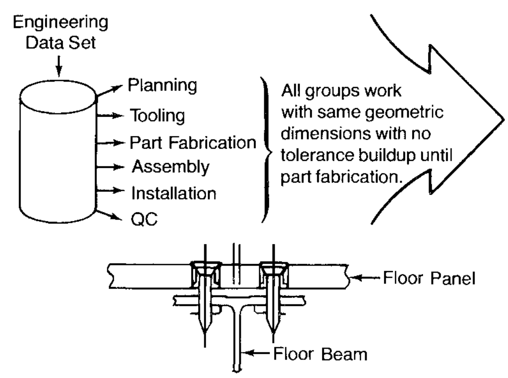

Fig. 16 Floor panel fabrication using shared environment.

Baseline Planning

Incorporating new technology is difficult during peak production loads. Skilled labor must be applied to the design and manufacture of the new product. Resources are more limited and risk is higher.

The production lull in the early 1980s has provided the right opportunity to incorporate new technology without great risk. The questions are "how much?" and "when?" There is a delicate balance between technology development and product development.

As shown in Fig. 13, technology development is always ahead of production capability, and the difference at any point in time must be understood. To tie in technology with production use, people in all segments of the design and build process are providing information about current, successful CAD/CAM applications like those mentioned in this paper. Each concept must be evaluated for its return on investment. The immediate result is a cost-effective synthesis of proven use and new technology. As each application is incorporated into the current capability, the capability improves.

Transition

The transition fron a manual mode to partial automation has already taken place. The transition from partial automa-

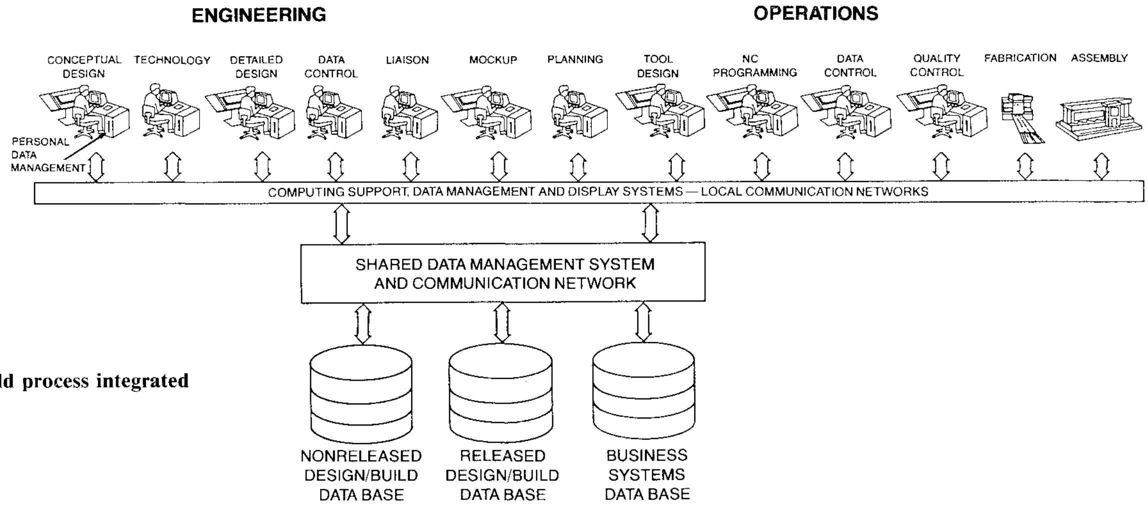

Fig. 17 Design/build process integrated by digital data.

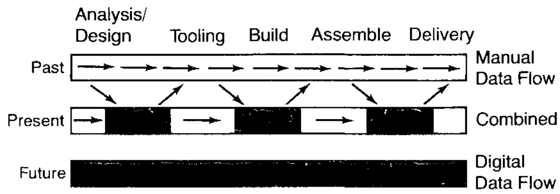

Fig. 18 Integration of sole authority digital data.

tion to full automation will be more difficult. Revising old drawings and data sets to comply with new standards would not be cost-effective. As new engineering is released and new derivatives and programs are initiated, wider use of digital data will be implemented. For a few years, then, three systems of data will be retained, as shown in Fig. 14. However, the framework is in place for replacement of manual methods, and eventually full integration of automated processes will occur.

Implementation Planning

As experience is gained with the fabrication of two-dimensional sheet metal and nonmetal parts (floor panels, ceiling panels, etc.), preferred methods will be expanded to support the design and production of more complex parts such as five-axis, numerically controlled machined parts. By the end of 1984, up to 53% of all production parts for new aircraft designs could be fabricated using CAD/CAM processes (Fig. 15).

Many of the processes implemented to accomplish this goal will be usable for more complex applications. This building-block approach to advancing technology is an educational effort. As manufacturers learn more about simple tasks, it is easier to make sound decisions about more complex tasks. In order to capture the full benefit of CAD/CAM, digital data must become the sole authority for the product definition. To aid in manufacturing the product, the data must be in a "shared" environment in a format that each department within the manufacturing company can use. To grasp the importance of this effort, consider that tooling, planning, fabrication, assembly, and inspection functions all require hole location data. When it is available to all in digital form, the accuracy of the engineering intent is retained until part fabrication. For example, when data defining holes in floor panels are used to drill and fabricate the floor panels and the floor beams, the parts are certain to fit (see Fig. 16). Accurate hole locations in detail parts allow the opportunity to eliminate subassembly tooling by matching holes to locate parts during installation. Traditional tooling locates parts from edges because hole locations were not accurate.

Design/Build Process

Figure 17 shows an integrated, fully automated future environment that will support a totally digital, auditable product definition. From design layout through final assembly, data will be available in a controlled digital format that can be used for all manufacturing functions. The key to this process is a shared data management system that allows closer ties and faster interaction among design and manufacturing departments and between design and build functions. This system will provide access to controlled nonrelease and release geometry and bill-of-material (parts lists) information residing in central data bases.

Currently, two information-handling systems—manual and computerized—must be maintained (Fig. 18). As new design is implemented, however, digital data will be used as the sole authority for new product definitions.

Conclusions

Experience illustrates that CAD/CAM tools offer speed, accuracy, and dependability. Integrated CAD/CAM holds even greater potential to reduce tools, ensure accuracy, and shorten flow time.

Computer application experience has allowed manufacturers an opportunity to extend computing tool use. Totally digital product definition is now being implemented for new designs. This means that the manually produced drawing will be replaced with digital representation of parts. The transition from drawing to digital data is a challenge that requires strong upper management support and a work force willing to aggressively incorporate productivity improvements into its environment.

Digital product definitions will be the controlling authority in future products, allowing build organizations (planning, tooling, numerical control, assembly, etc.) to use common design data. Because data are enhanced (added to or subtracted from) but not changed, the accuracy of the data is retained until part fabrication. CAD/CAM provides more accurate detail parts, resulting in superior assemblies that require less shimming on installation. Improved geometry control from engineering through manufacturing extends product life and, thus, lowers the purchaser's operating cost.

CAD/CAM use will accelerate. The use of computing tools extends people's capability. This technology, blended with existing design/build techniques, gives manufacturers the ability to continue production of reliable quality products with controlled costs.

References

[1]Wehrman, M.D., "CAD Produced Airplane Aircraft Drawings," AIAA Paper 80-0732, 1980.