AIAA 80-0732R

CAD Produced Aircraft Drawings

Marvin D. Wehrman*
The Boeing Commercial Airplane Company, Seattle, Wash.

The Boeing Company has expanded the use of computers to include the preparation of engineering drawings. The system utilized is a combination of large host mainframe and minicomputers. This combination is tied together with a network called the CAD/CAM Integrated Information Network (CIIN), which allows data to be transferred between machines and also to be stored and retrieved from a common geometric data base (GDB). Engineering drawings are produced using a combination of general and special batch automatically programmed tool (APT) programs on the mainframe and then completed on the interactive computer graphics (ICG) system. Drawings are also originated on the graphics computer. Data can be accessed from either system and this data is available to other design groups like payloads, controls, hydraulics, powerplant, electrical, etc., as well as manufacturing.

Introduction

THE Boeing Company began using computers to aid in the building of airplanes in 1958. At that time manufacturing created automatically programmed tool (APT) programs to describe parts shown on engineering drawings. That data could then be used to create a punched paper or mylar tape and make machine parts. This procedure is well known as numerical control (N/C) machining.

Boeing used special batch APT programs on the YC-14 (an Air Force transport aircraft designed in 1972) to make engineering drawings for wing inspar ribs, wing leading-edge ribs, and some body frames. The computer-defined geometry of these assemblies allowed the prototype wing box to be assembled without the use of unplanned shims. This procedure for creating drawings was an extension of the N/C technology that used the computer to drive a pen in lieu of driving a cutter to make a machine part.

In 1974 the Boeing Commercial Airplane Company brought in the first interactive computer graphics systems. The advent of interactive graphics to The Boeing Company marked the beginning of a new epoch in computer-aided design because of its reciprocity. This dimension allows designers to "talk back and forth"—to interact—with the computer and to realize the results of their work immediately. The use of interactive graphics has magnified the scope of the use of computers and the effectiveness of batch programming, has narrowed the gap between the design and manufacturing, and has opened up new possibilities for excellence in all design projects (i.e., structures, systems, payloads, and propulsion).

How Designers Use the Computer

The 767 project (Boeing's new twin-engine, 200-passenger commercial jet transport) has used computers to perform an increasingly large volume of design work. This work was accomplished in three ways (see Fig. 1). The first two of these methods rely on direct access to the large host computers housed in the data centers at the Boeing Renton and Kent facilities. The third, (ICG) includes primarily the on-site stand-alone minicomputer system which encompasses all the graphics and annotation functions. Specific tasks work best with each of these applications.

Conversational time sharing (CTS), Kronos interactive time sharing (KIT), time sharing option (TSO), and master dimension definition (MDD) lofting programs all serve as design aids in mathematically defining the components of the airplane. The general and special batch APT programs contain a tremendous amount of geometry that manufacturing is able to use for tooling and fabrication of parts. These programs are located in the large host mainframes.

What We Have Learned

The Boeing 767 program enjoyed the advantage of the experiences of previous aircraft programs' utilization of computers in design. There now exists a documented history to assist engineering in determining the percentage of CAD penetration (the amount of computerization).[1]

Part cards and drawing sheets are indications of the amount of design work and geometric entities. Historical data for the design of existing Boeing airplanes and the YC-14 was available for analysis and comparison. This data has been accumulated in four major areas of endeavor: structures, systems, payloads, and propulsion. We (the 767 Program) achieved our planned CAD penetration of approximately 18%.

There also existed for our benefit the successes and failures of other efforts and experiences from which to plan direction. Developmental work was done with various kinds of interactive systems. Each of these systems is more successful in certain applications than in others. This conclusion was reached in part by studies and in part through trial and error. We gained from our experience in the real-time, production environment.

We learned the most effective combinations of interactive and batch, of divergent types of graphics systems and plotters, and of manual and computerized drafting.

More generally, we learned that computers are very powerful in terms of geometric manipulations, especially for self-checking capabilities. We have learned, as with any tool, that there is a right way and a wrong way to use computers. We try to find applications that are productive and build on those, and to eliminate situations that are not productive. For example, on single end-item parts, it takes more time to build it up on the computer than for a drafter to do it by hand. With assemblies or multiple usages of parts or where the data set is beneficial to manufacturing, we turn to the computer.

The use of computer aided design in The Boeing Company

Presented as Paper 80-0732 at the AIAA/ASME/ASCE/AHS 21st Structures, Structural Dynamics and Materials Conference, Seattle, Wash., May 12-14, 1980; submitted June 3, 1980; revision received Aug. 14, 1980.

*Chief Engineer, 767 Structural Design. Associate Fellow AIAA.

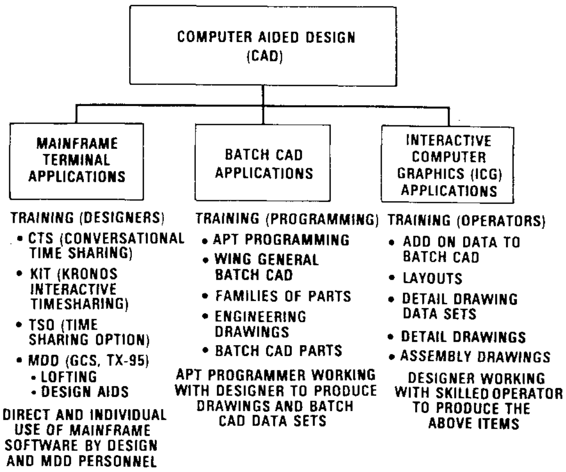

Fig. 1 CAD work is accomplished in these three ways. The first two, mainframe terminal applications batch CAD applications, rely on direct access to the large host computers. The third, ICG, includes primarily the on-site, stand-alone minicomputer system.

has been a slow, gradual process over the years, incorporating each change and technique that has been successful.

How Structures Design Use Computers

Taking geometric information from the geometry control system (GCS), Structures Design Project began the airplane final design. The preliminary design GCS loft provides the basis for the master dimensions system and the airplane final design. The GCS creates such data as the kind of airfoil required to make the plane fly, basic lift and drag capabilities, wing size, etc.

Loft Data

When loft surface requirements come back from the wind tunnel and preliminary design, loftsmen mathematically create a surface definition. They begin writing batch CAD or TX95 extractions to cut contours. It is the CAD group's responsibility to create software packages for jobs the design group wants them to do. Requirements from marketing, preliminary design, technical staffs, wind tunnel, and project design are analyzed. Input from all groups must be considered.

Beginning from layouts, project designs toward the class II mockup release. For the first time they create detail designs. They settle on a final centerline drawing, then decide stringer spacings. In addition to the master dimensions definitions, conversational time sharing, Kronos interactive time sharing, and time sharing option all serve as design aids in mathematically defining the components of the airplane. The general and special batch CAD programs contain a tremendous amount of geometry which manufacturing is able to use for tooling and fabrication of parts. These progams are located in the large host mainframes.

In January of 1979 when the mockup of the model 767 was assembled, the mockup organization judged it to be the most outstanding mockup the commercial airplane company ever built. The mockup shop attributed this success to the completeness and accuracy of the drawings. For example, a separate CAD drawing was produced for each body frame, rather than a typical frame with a list of exceptions.

Conversational Systems

The large host computers, housed at the Boeing Renton and Kent, Washington, facilities, are used primarily in two ways by the structures group: direct access to call up conversational design aid programs, and general batch and special batch programs. The 767 structures project used as design aids some universally-available programs that are located on the large host computers. These programs are accessible through the CTS and KIT programs.

About seven years ago Boeing developed some conversational analysis programs. Before that time the only computing support for designers was large batch programming. Input to these batch programs was in fixed-field data format, understandable to a computer programmer, but mysterious and confusing to designers. The designer had to explain his problem to a programmer who then sent the job to a computer. The output came back to the programmer for checking, then to the designer for rechecking. This back and forth process led to long waits, demoralizing to engineers and devastating to design schedules. As a result, designers often returned to manual methods. Then computer time-sharing came into being, allowing the designer to work directly with the computer. Communication between the user and the computer is direct, and output is immediately displayed as printouts and/or graphic plots.

The programs print out questions in designer terminology; that is, in English, just as one designer talks to another. To make it easy for the user, the programs ask only three types of questions that may be answered by 1) a *yes* or *no*, 2) the number of a multiple choice, and 3) number values such as dimensions, location and magnitude of loads, coordinate of points, etc.

Although this data is stored at remote sites (40-50 miles away) it can be accessed from terminals at the 767 site located in the Everett, Washington plant.

General Batch Programs

The batch process, using the APT language, is a parametric design, or design geometry, in combination with the MDD (lofting) programs. In this mode some parts are stored on the computer so that manufacturing engineering can access the structural geometry of the aircraft parts. The primary advantage of the batch process is its capability. Batch programming is very effective for contour-related families of parts, such as inspar ribs, body frames, leading-edge ribs, etc.

During the development of the YC-14, batch programs were initiated that pioneered the use of batch CAD. However, due to geometry differences and software construction, these programs were not readily usable on subsequent aircraft design programs. Following this experience, central engineering began creating several large general programs that incorporated macros (parts or components which are preprogrammed). The general programs could then be adapted to any Boeing commercial aircraft configuration. These first general batch programs were for wing-box structures (Fig. 2) and body monocoque (Fig. 3).

Preceding the 767 Program

For two years preceding the 767 Program, a team of batch CAD programmers were able to accomplish a tremendous amount of upstream work, eventually moving on site at the Everett plant to work on the 767 Project. Wing inspar structure, body monocoque, and nacelles were defined. Additional family-related programs were also programmed in order to provide layouts and drawings for additional items such as the wing leading edge and trailing edge. The general batch programs for the wing were modified further (same program, revised geometry) in order to support the mockup releases for the empennage. Initial support of the empennage structure was minimal. However, as the vertical stabilizer was relofted and revised late in the design program as a result of design changes, the program was of considerable value in support of the redesign effort.

We now have a data base of general and special batch programs on file whose worth is immeasurable. Using a combination of batch programs and interactive graphics, drawings such as skin panels and stringers can be manipulated to be presented on standard engineering drawing forms. These large parts (some 65 ft long) would be unmanageable to detail entirely in a batch mode to produce full-scale drawings (see Fig. 2).

While batch CAD can generate multiple look-alike drawings rapidly, there are certain phases of drawing development that lend themselves better to an interactive visual mode. Having written a batch program 60 leading edge ribs can be created overnight. But batch CAD does an inefficient job of putting words on the drawing. To make something unique on any one of those 60 drawings and to program it in batch mode is too much work for that one exception. But if you marry the two, the ICG system can do the unique job.

The wing design of an airplane, one of the most complicated and critical structures, has been transferred in the form of APT programs to the graphics system for refinement and completion of detail drawings.

Special Batch Programs

Special batch programs, those that were created and not taken from the stockpile of previous general programs, were written for the fixed leading edge, the leading-edge slats, the fixed leading-edge machined ribs, and the trailing-edge flaps. These are ideal special batch applications because they are families of look-alike contour-related parts (see Fig. 4). The basic geometry for either the actuators or the tracks can then be combined with the contours for a perfect geometric fit. A program for the whole series of leading-edge ribs and slats can be created with the contour as the only basic variable. Special batch programs become very powerful to the overall development of structural design and have a high productivity rate for look-alike families of parts.

Interactive Computer Graphics

The design of an airplane generates a number of large, unwieldy drawings when dealt with at full scale. For this reason certain activities in the design phase can be handled on a graphics plane, with the aid of a visual, interactive device. Interactive computer graphics (ICG) systems are used in a variety of ways. While batch CAD can generate multiple look-alike drawings rapidly, there are certain phases of drawing development that lend themselves better to an interactive visual mode.

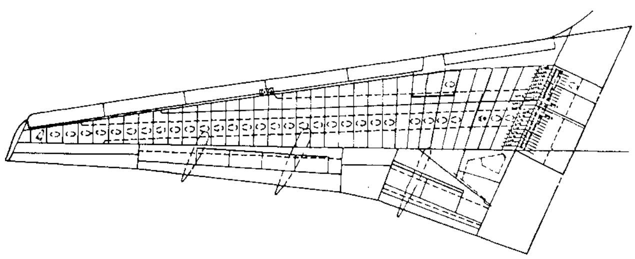

Fig. 2 Wing centerline drawing.

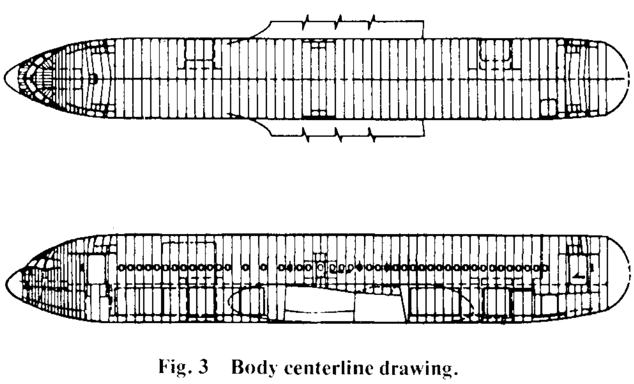

Fig. 3 Body centerline drawing.

ICG encompasses several main functions: a visual real time display, the production of a data base of engineering parts design, the development of a pattern library, the maintenance of a data management system, and the use of a plotting system. These functions operate on the minicomputer system configuration, with communications links between the ICG and large host systems for storage, access of APT and MDD programs, and communications between ICG systems. The systems provide the capability to generate, store, revise, and verify geometry.

The 767 Project uses a number of batch and ICG combinations varying in their ratios. For example, wing inspar ribs were begun with a general batch program, then brought onto the ICG system for completion (see Fig. 5).

We used interactive graphics in many areas. Payloads, as an example, used the leveling capability of the interactive graphics system extensively to assist in the design of aircraft interior arrangements. Graphics entities can be separated on different levels, or locations, on the disk at the discretion of

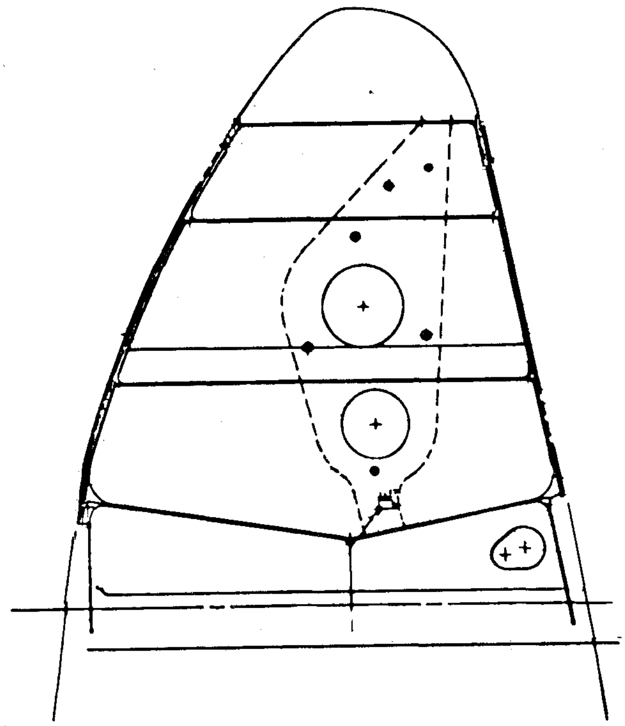

Fig. 4 Leading-edge rib.

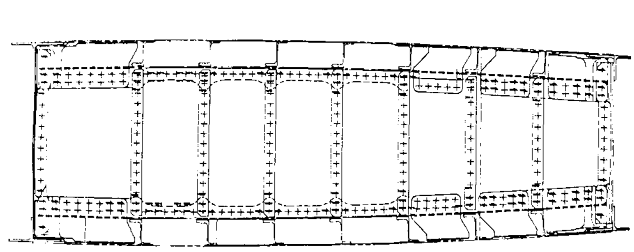

Fig. 5 Wing inspar rib.

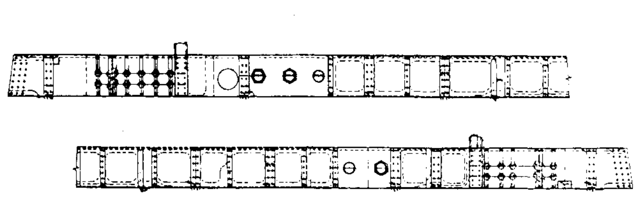

Fig. 6 Composite floor beam.

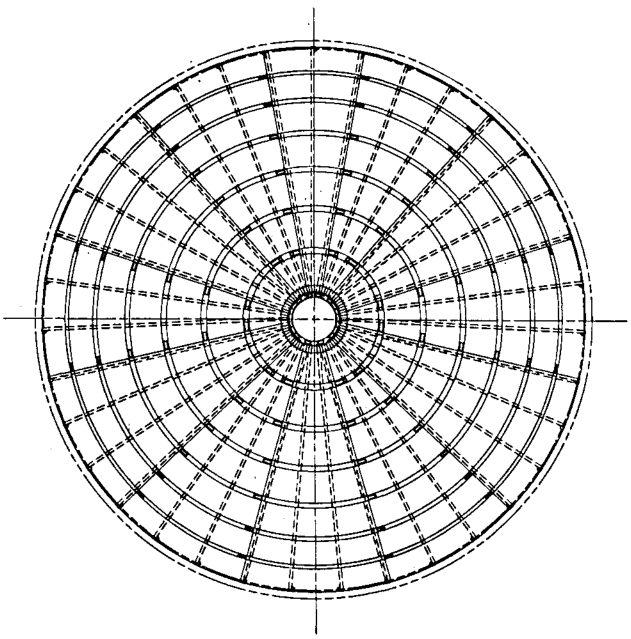

Fig. 7 Aft pressure bulkhead.

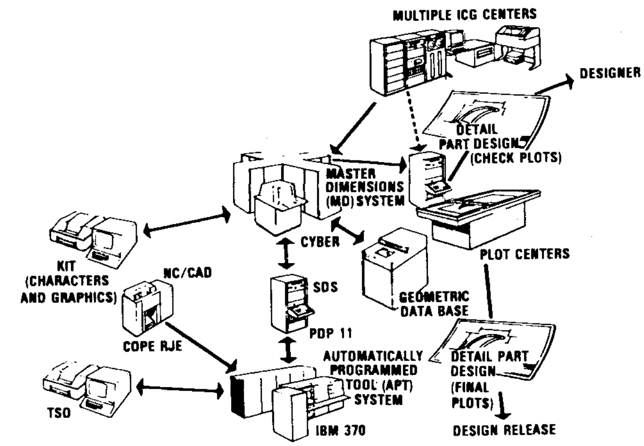

Fig. 8 Flow of data through the systems used by the 767 CAD organization.

the user. An example of this technique is when payloads engineers insert seats, lavatories, galleys, etc., each on a different level. Using this method, payloads can custom build interiors for each airplane depending on its requirements. With this capability the designer can manipulate data on one level without disturbing data on another level.

An example of assemblies that are built from scratch on the interactive graphics system are floor beam assemblies (see Fig. 6). The leveling capability works for floor beams in the same way it does for payloads. We put fasteners, webs, stiffeners, chords, and cutouts on different levels. All levels can be called up as a composite at any time for assembly and installation drawings.

We used interactive graphics on the aft pressure bulkhead (see Fig. 7). An engineer less than a year from graduation, using existing 747 pressure bulkhead drawings and instructions from his lead engineer, produced 14 sheets of stable mylar drawings on the ICG for the mockup that was faster and more accurate than creating the mockup drawings by hand. Further activities on the ICG include the penetrations for fuel lines, air lines, and wiring that runs through the bulkhead back to the auxiliary power unit (APU) and the control surfaces in the empennage.

After a slow start due to shortage of manpower, postprocessor disparities, and trying to translate back and forth between several command languages, the CAD interactive graphics efforts paid off. The value of complete computer-generated drawings cannot be overemphasized, especially in structural geometry definition, such as body frames, that require interface coordination with payloads and systems.

How It Is All Tied Together

Another problem the 767 program encountered was the geographic distance between people and systems, and the differences in computer languages, that made it necessary to develop a global communication link between all these systems. Although the activities using computers take place in several different forms (interactive graphics, batch programs, lofting programs, conversational systems), Boeing devised a method for tying the data together. Through a link and a data storage device called the CAD/CAM integrated information network[2] (CIIN), these functions can relate to one another. Engineering can now call up or send data stored on other systems, like or unlike, on the large hosts, or from manufacturing. (Refer to Fig. 8.)

For many years such data as master dimension definition and batch CAD programs were passed back and forth via magnetic tape. Then, when interactive graphics came on the scene, the need for a more efficient, less primitive method for exchanging this data was apparent. At the same time, during the early and mid 1970s, processing became less expensive. Minicomputers and intelligent terminals became feasible. Design work on the 767 exists in a heterogeneous environment, but has become centralized through the distributed communications capabilities of CIIN.

Common Geometric Data Base

We have established a common geometric data base (GDB) whereby geometry can be input to the data base from structures, and be used by other groups such as systems, payloads, or powerplant, as needed to go through the design process. From these disciplines within engineering, the data is available to manufacturing to build tools and parts from released data sets.

Conclusion

It has been an exciting and difficult design program for the 767 design groups, but the difficulties have been tempered by the successes. Never before has the need for effective interplay between unlike systems and processes been so pronounced. Some of the problems have stemmed from the human aversion to change. People were reluctant to change their way of doing things. This problem was alleviated through training and the increasing success of CAD systems. The Boeing 767 project, in its endeavor to bring all of these domains together with the aid of the computer and a dedicated work force, is committed to building the best airplane ever built. In the future, we intend to capitalize on our experience and increase the amount of CAD penetration within the 767 project and to pass on our experience to future programs.

References

[1] Beeby, W.D., "The Application of Computer Aided Design to the 757 and 767," AIAA Aircraft Systems and Technology Meeting, New York, 1979, pp. 79-1853.

[2] Braithwaite, W.W., "Boeing's CAD/CAM Integrated Information Network," AIAA Aircraft Systems and Technology Meeting, New York, 1979, pp. 79-1847.