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DRAPO
INTEGRAL COMPUTER-ASSISTED DESIGN AND MANUFACTURING SYSTEM

F. Bernard
Head of the CAD/CAM Department
Avions Marcel Dassault - Bréguet Aviation
Saint-Cloud, France

Abstract

The search for maximum optimization in the achievement of more and more sophisticated aircraft has led the Avions Marcel Dassault - Bréguet Aviation company (AMD-BA) to gradually implement a system for computer-assisted design and manufacture. The name of this system, "DRAPO", means "Définition et Réalisation d'Avions par Ordinateur".

DRAPO can be defined both by the equipment adopted, the selection of which determines the field of application as well as the utilization mode, and by its major functions.

The purpose of this report - after a short introduction describing the motivations and objectives established by the AMD-BA company in implementation of this system - is to describe the major aspects of the DRAPO hardware and software and to illustrate its use through a few examples. Further on there will be a discussion on the new ground in research channels it seems essential to break as quickly as possible in order to ensure ever-increasing and beneficial use of this new technique, especially in the tridimensional field.

I. Introduction

Simultaneous development of theoretical aerodynamics, the computations of which are the first step toward aircraft design, and numerical control machining, which is the last operation in achievement of main structural parts or tooling, is at the origin of the DRAPO system.

Indeed, over the last fifteen years, theoretical aerodynamics, whose computation processes have considerably advanced thanks to the ability of computers to process large equation systems, is at the origin of a search for accurate definition through data processing of complex surfaces forming the aircraft skin. At the same time, increasing use of N.C. machines has resulted in the search for numerical definition of the geometry of structural parts.

Ever since, total computerization of the aircraft design and manufacturing procedure has become unavoidable and has been gradually achieved. The computer resources justify this development:

The use of a single, practically unlimited data bank, doing away with the conventional, consecutive and fastidious transcription operations, guarantees integrity, accuracy and coherence of the results. Furthermore, the techniques for dialogue with the computer, whose field of application rapidly increases with progress made at the graphic terminal level, the speed of computation and the memory size, offers the user a much more efficient decision-making instrument.

Therefore, the structure of scientific and industrial data processing is organized around a single data base. More and more this base is managed by interactive programs, batch processing being only justified for major computation runs (e.g. theoretical aerodynamics and structural analysis) or for automatic sequences at the end of the procedure (e.g. filing, plotting and machining).

Today, these data processing techniques make it possible to obtain products which would not have been conceivable using conventional processes: DRAPO has thus become the essential instrument in design and manufacture of our aircraft.

II. Hardware

Six plants of the company have computer centres equipped with the DRAPO system, according to the schematic organization shown in figure 1.

2.1. Computers

The DRAPO system uses IBM computers. Except for the Saint-Cloud plant, which is specialized in major scientific computations (theoretical aerodynamics and structural analysis in particular), the DRAPO system sizes the required dimensions on each site. The Saint-Cloud plant has an IBM 3033 computer with 12,000 K-bytes of core. Nevertheless, DRAPO uses 25% of the daytime resources of this core. The specific needs of the company's other plants have determined selection of the model in the 370 series (138 to 158) or, more recently, in the 4300 series (4331 and 4341).

2.2. Dialogue means

There are numerous interfaces between the operator and the central processor: alphanumeric terminals (type IBM 3278) or interactive graphic terminals (type IBM

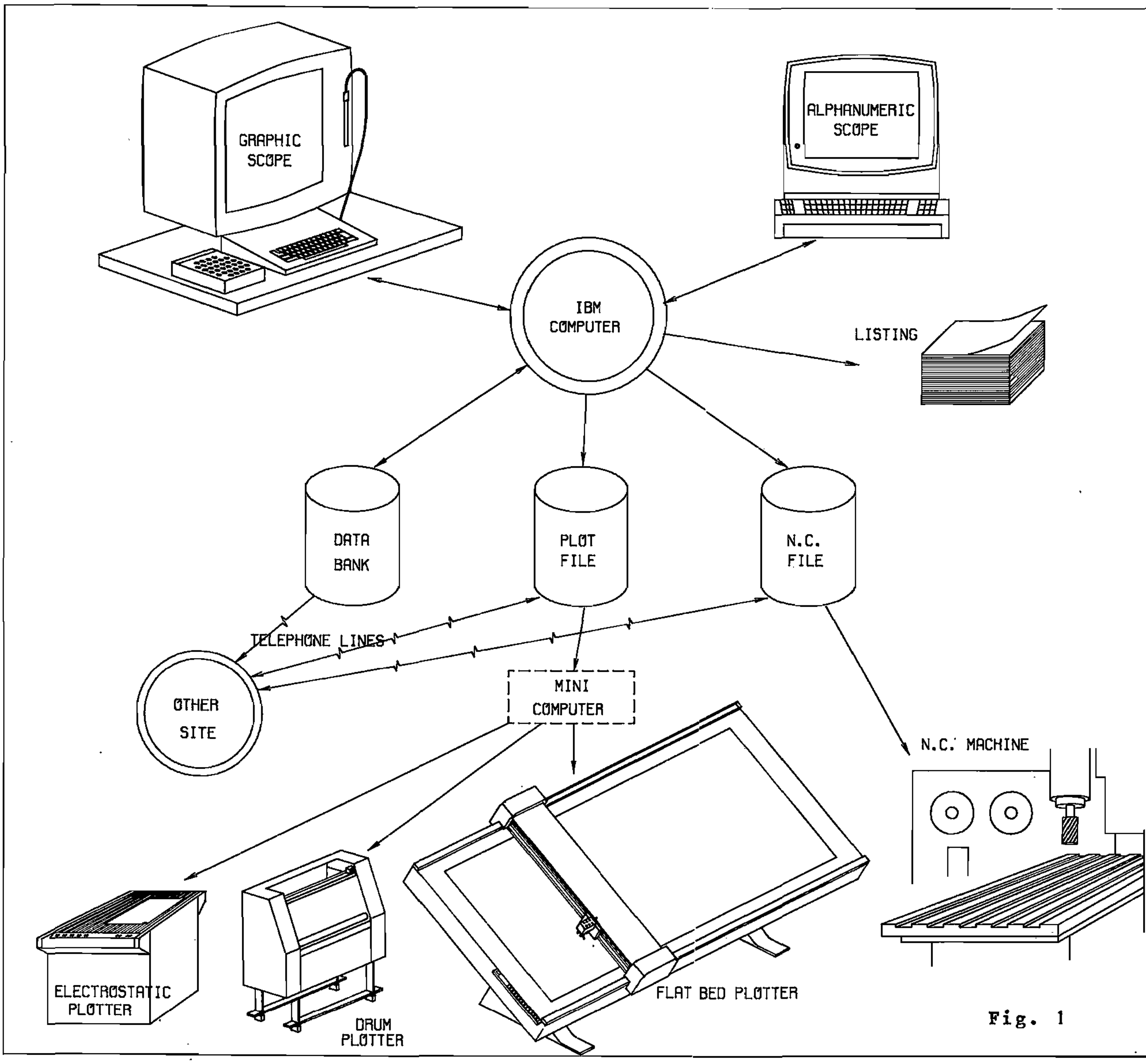


Fig. 1

2250, ADAGE GT/2250 or, more recently, IBM 3250 and ADAGE 4250). Some sixty graphic consoles are located throughout the six plants.

The operator has at least an alphanumeric keyboard and a screen - the essential instruments for dialogue with the computer. The interactive graphic terminals display points, vectors or characters and provide two further dialogue devices: a light pen and a 32-key function keyboard.

Each key of the function keyboard is associated with a specific task: by pressing one of them, the operator triggers interactive-mode processing using the alphanumeric keyboard and the light pen. This pen is a very precious instrument for fast selection of the elements displayed.

The display is constantly refreshed: this basic feature, which distinguishes this type of screen from the "storage" type CRT, enables instant, permanent updating of the picture and considerably facilitates dialogue.

2.3. Plotters

One or more plotters on each site are connected to the local computer, either directly or indirectly via a mini-computer. This last configuration permits last-minute decisions as to the destination of a drawing and relieves the central computer of certain specialized computations.

The local needs justify the selection of these terminals based on their characteristics. They are either drum plotters (Benson) which are inexpensive and relatively fast, or large flat-bed plotters which are real machine-tools capable of high-precision plotting with nibs on Mylar or diamond scribes on "tracing cards".

More recently, use of electrostatic plotters (Versatec) has been made in design offices. Their operating principle makes them extremely fast. Furthermore, their accuracy and resolution can be compared to that of drum plotters; for instance, they can generate a complete drawing of an aircraft main frame in just a few minutes.

2.4. Teleprocessing

Present technology does not yet make it possible to establish long-distance, real-time communications between computers: the amount of data required by the DRAPO system is incompatible with the maximum available flow.

Nevertheless, the computers of each plant are interconnected by telephone lines enabling transfers between disk files, at all levels and at each step of the DRAPO operating procedure.

Thus the shapes - complex surfaces, geometry of parts - which are only determined in the plants having a drawing and design office, are transmitted to the manufacturing plants.

These links improve distribution of the work loads and optimize use of the equipment, some very specialized units of which are not available on all sites. This is the case of very large-dimension drawing machines (7.2 x 1.8 m) in particular.

III. Software

The DRAPO software is a product of a team of technicians and engineers specialized in data processing (at the system level), mathematics and dialogue techniques.

3.1. Overall DRAPO structure

Basically, DRAPO is an assembly (see figure 2) of two large, highly compatible and complementary interactive modules respectively specialized in bidimensional and tridimensional applications, with a set of batch service programs surrounding the basic assembly.

For the time being, this assembly, which is almost "transparent" for the operator since the links are automatic and instantaneous, seems to be an optimum solution for sharing of the computer resources. Indeed, bidimensional processing consumes three to four times less storage space and computing time than well-optimized tridimensional processing. In other respects, experience shows that, when possible, working on a plane is within the capabilities of a larger part of the staff.

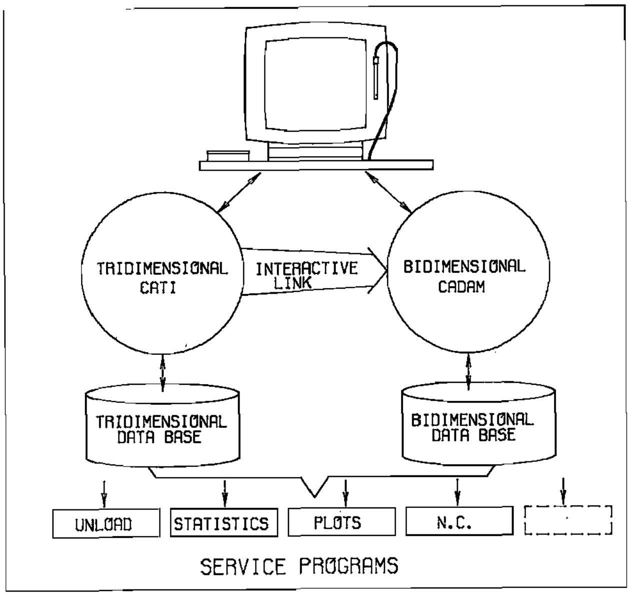


Fig. 2

a) Bidimensional interactive: CADAM + AMD-BA contributions

In 1975, the AMD-BA company purchased the CADAM program (Computer Graphics Augmented Design And Manufacturing, marketed by the Lockheed Company, California, U.S.A.) and further developed it through the addition of new possibilities. This large module with its 85,000 statements, 15,000 of which have been written by AMD-BA, mainly handles bidimensional entities but also has interesting extensions to tridimensional applications.

b) Tridimensional interactive: CATI

CATI ("Conception Assistée Tridimensionelle Interactive") is a product which has been entirely developped at AMD-BA as a replacement for the old complex shape design and operating batch programs. This large module with about 90,000 statements, which is constantly being developed (about 1000 additional statements each week) handles tridimensional entities at the highest level: complex surfaces, solids.

c) Batch service programs

They are adapted to management of the data base (e.g. filing on magnetic tape) or to measurement of computer activity (e.g. statistics, accounting). Some end-of-procedure computations, downstream from interactive processing, are also batch processed: generation of plots or numerical control tapes.

3.2. CATI structure

The structure of a large interactive system is dictated by the concern to ensure development which is as flexible as possible considering its size (several scores and even hundreds of thousands of statements), the large number of persons who simultaneously develop it and the periodic hardware improvements which can have consequences on the software.

This structure includes three logic units (cf. figure 3): the monitor, the application support and the application.

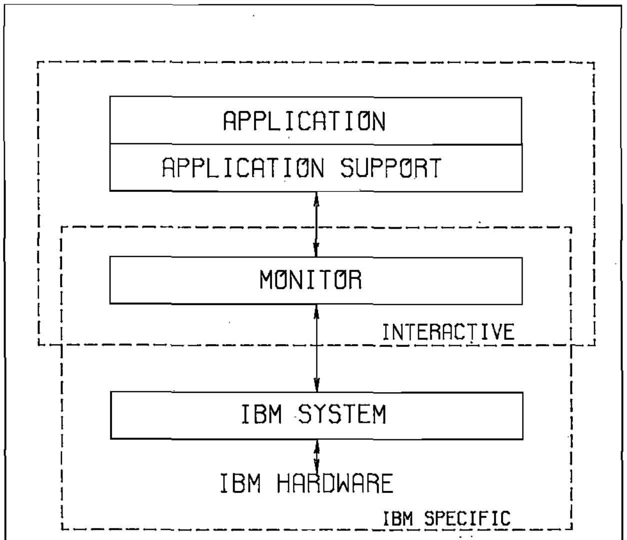


Fig. 3

3.2.1. Monitor

The monitor, which is close to the IBM system and hardware, is written in assembler language and ensures independence of the applications with respect to the hardware.

It handles the following four main functions (cf. figure 4):

a) Program control

Communications with the operator console, dynamic allocation of the consoles, automatic program restart in case of a failure, safe-keeping of the operator's work at regular intervals, time sharing among several graphic consoles, loading in memory of the application programs stored in the disk library.

b) Dialogue management

Taking into account (via the alphanumeric keyboard, the function keyboard or the light pen) and display of the interactions. All the possibilities of the current IBM consoles (IBM 2250, IBM 3250 or compatible consoles) may be used.

c) Access to the data base

The disk-store data base is simultaneously shared by several interactive or batch users and by several computers if the hardware configuration so allows (this is the case for the Saint-Cloud plant).

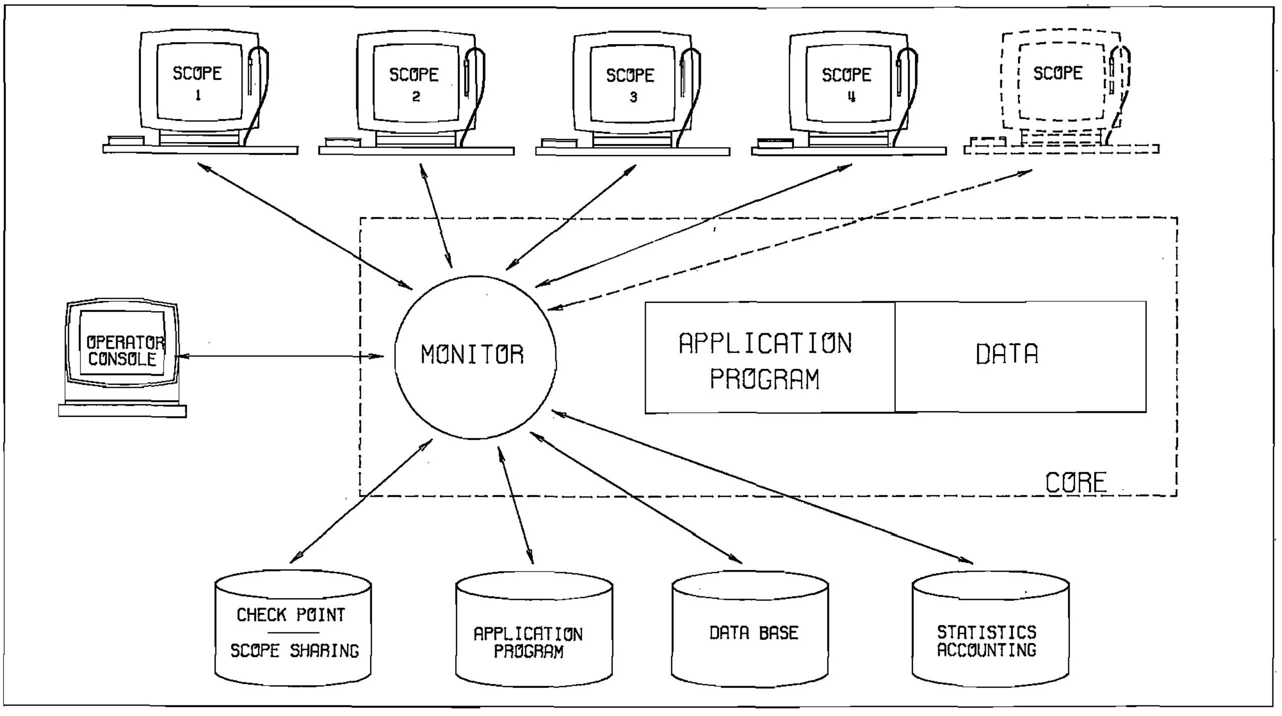


Fig. 4

d) Statistics and accounting

Disk-file storage of the activity of each console (number of interactions, computation time), the performance levels (response time) and task sharing (accounting).

A batch program prints out daily summary plots which enable easy system and computer control.

3.2.2. Application support

This support groups all the general dialogue and management tools needed to manipulate elements in 2- or 3-dimensional space. It is independent of both the hardware and the applications developed and performs four functions with specific associated software:

a) Storage data management

The elements (points, straight lines, surfaces, solids, etc.) may be grouped at will in sets to be subjected to common processing operations. The following are associated with each element: an identifier, a mathematical representation, a graphic representation which may be modified at will, attributes defined by the operator and a history storing the operations carried out to create it. (cf. figure 5).

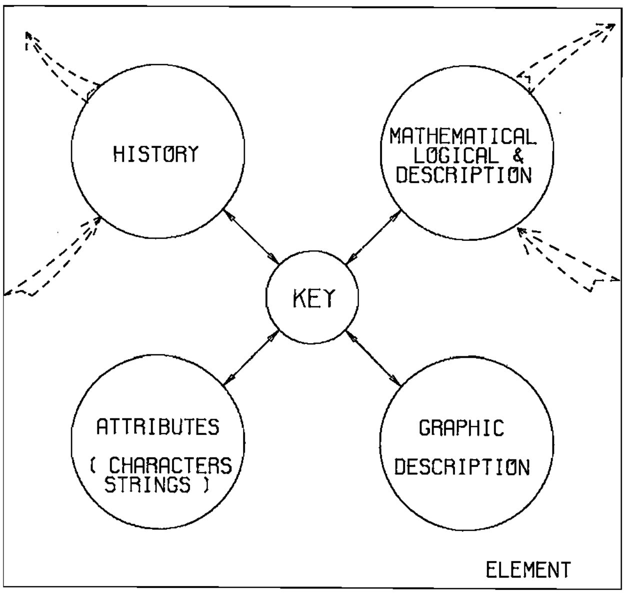


Fig. 5

b) Picture manipulation

The operator can generate one to four pictures (or views) on the screen and manipulate them (change of scale, rotation, translation, etc.). He can also modify the characteristics of each displayed vector by changing the brightness, the texture (solid line, dotted line, combination of the two) and the state (steady or flashing).

c) Disk-file data base management

The operator can create, erase, write or read all or part of the data stored on disk and assemble all or part of several groups of data. In addition, he can automatically transmit any plane sub-assembly generated by CATI in the CADAM bidimensional data base.

d) Dialogue assistance

This software, which is a dialogue standardization and programming simplification element, groups a set of subroutines used in the application.

3.2.3. Application

For each application there is an associated specialized key on the function keyboard and a program stored on disk. Selection of a key results in transfer to memory of the associated program via action by the monitor, establishment of the connections with the data common to all the functions and sequencing of the requested application.

The operator first chooses one to twenty-one functions he wishes to manipulate simultaneously from a library, depending on the problem he wants to handle. (Since the keyboard has thirty-two keys, eleven of them are actually set aside for the application support: erasing, picture manipulation, cancelling of an operation, access to the data base, etc.). These functions may, for example, be definition of a point, a straight line, a surface, a solid, a machining operation, a kinematic, etc.

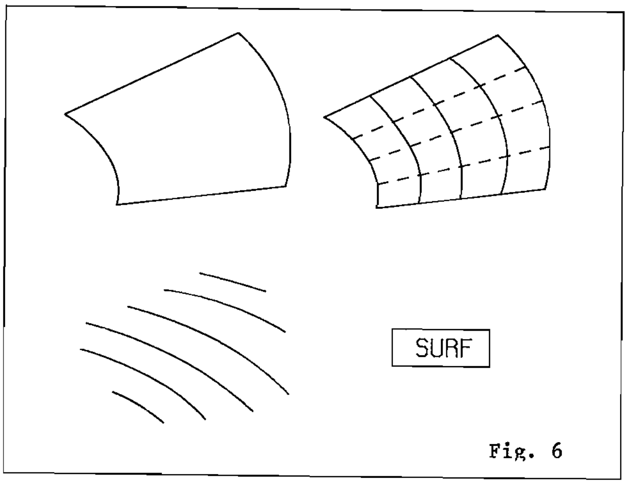
3.3. Dialogue

Dialogue is defined so as to obtain maximum reduction both in the training period (a few days) and the operator's written documentation, and in the number of interactions for each application handled.

At all times it is the program, and not the operator, that proposes the actions: selection of a menu article or an element, doubt removal indication, use of the function or alphanumeric keyboard. For each interaction there is a corresponding type of processing which is clearly indicated beforehand and systematically materialized through a modification in the picture.

The operator can work in the bidimensional mode by designating a plane: this simplifies the dialogue, even though the data generated are still tridimensional.

The graphic representation of an entity may be modified at will: this option is practically indispensable for manipulation of surfaces or solids on present-day screens (cf. figure 6).



4 graphic representations of the same surface

Each element is identified by its picture and by a chain of characters; consequently, during dialogue, selection may be made using either the light pen or the alphanumeric keyboard.

A permanently activated key makes it possible to cancel the last operation performed.

Manipulation of the picture (on one to four views) independent of processing is possible at all times: this feature prepares the advent of more "intelligent" consoles provided with a scale-change, rotation and translation processor.

An analysis function which is mathematical (e.g. What is the equation of this plane?), relative (e.g. What is the distance between these two points?) and, above all, logic (e.g. On what surface(s) is this curve plotted?) is an effective aid to comprehension of a complex picture.

Finally, the history may be analysed on an alphanumeric screen in order to reproduce the definition mode for an element in plain language (e.g. How was this curve generated?). In addition, it also enables automatic reproduction of a topologically identical entity: the machine has stored the operator's know-how.

3.3. Mathematical algorithms

High-level mathematical algorithms have been developed to enable a maximum number of real-time processing operations. The intersection of two complex surfaces, for example, the result of which is a polynomial curve (and not a file of points), requires 2/100ths of a second of computation time on an IBM 3033 computer. Therefore, this computation time remains acceptable on a smaller machine.

IV. Major Applications of the DRAPO System

In its current state, DRAPO integrates three major functions. Each of them is an aid to the computer for the various chronological steps in aircraft design and manufacture: definition of shapes, drawing and manufacture.

4.1. Definition of shapes

This function, which was originally inspired by the requirements of theoretical aerodynamics, has gradually supplanted hand drawing. Today, it is the tool for definition of aircraft shapes: complex surfaces and internal references of frames, wings, ribs, etc. Little by little it is replacing the drawing mode of defining the structural parts: the designer constructs the solids directly in space.

The operator creates and manipulates all the geometrical elements in a plane or in space: points (by intersection, projection, etc.), straight lines (by intersection, projection, two points, etc.), plane (by equation, passing through points, straight lines or curves, normal to a straight line, etc.), text of various sizes and orientations, marking (in relation to another datum), linear transformations such as translation, rotation, symmetry, similarity, etc.

Further details are given below on curves, surfaces, faces and solids.

a) Curves

A curve may be the intersection of a plane and a surface, the intersection of two surfaces, an isoparametric curve, an apparent contour, etc. It results from a computation based on complex elements (curves, surfaces) created previously.

Some curves are defined by their type, such as circles and conics.

Finally, a curve may be defined as an interpolation function of an ordered list of points. Certain points have an associated tangential direction and a curvature, where applicable. The operator has the choice of two types of curves:

- the first one, computed using the finite element method and designated by 5th degree polynomials in each interval between two consecutive points, is the "smoothest" interpolation function guaranteeing continuity of the curvatures and even of their derivatives.

- the second one, computed by the least squares method and defined by a single polynomial having a degree of one to fifteen, is better suited to rapid design based on approximate points.

The graphic console displays the curve and its changes in curvature: experience then shows that, thanks to this quantitative representation, a small screen efficiently replaces a large conventional drawing table. The operator modifies the constraints as he pleases (points, tangents, curvatures) and instantly obtains a new curvature distribution. Conversely,if he assigns a tolerance to each point, automatic smoothing computation determines the optimal curvature.

b) Surfaces

Some surfaces may be defined by their type, such as spheres, cylinders or circular-base cones.

As a general rule, they are complex and are defined as an interpolation function of a network of points and curves on which transverse tangent and curvature constraints, if any, are placed.

They are mathematically defined by biparametric polynomial functions having a degree from one to fifteen.

c) Faces

A face is the region of a surface limited by one or more closed contours. It is defined extremely fast regardless of its complexity, by the description of its limit curves (cf. figure 7).

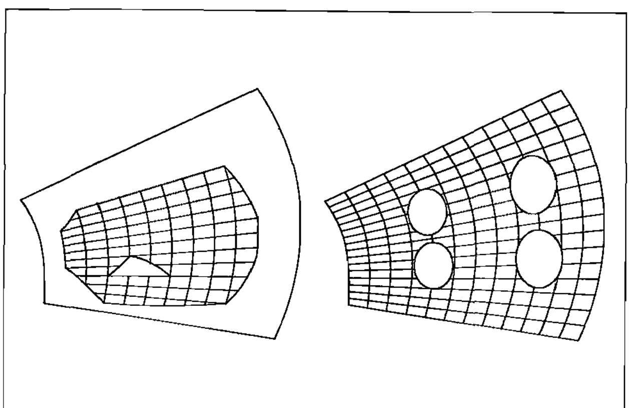


Fig. 7

d) Solids

A solid is the region in space limited by one or more closed borders defined by adjoining faces. It is generated by description of the border faces, regardless of its complexity.

All processing operations are possible (intersection by a straight line, a curve, a plane, a surface, another solid, numerical control, etc.). The solid addition and subtraction operations are currently being developped.

4.2. Drawing

The interactive graphic console has become the design office draughtman's new work tool. The screen takes the place of the drawing board; the light pen is used like a pencil and eraser.

The design technique is not changed. Indeed, according to the rules of descriptive geometry, the draughtsman studies the figures in space based on their projections on planes which are perpendicular to each other. A structural part is defined by its projections of rotated sections (possibly of the perspectives), in a bidimensional data base.

The designer can create points, straight lines, circles, conics, curves or texts. Where applicable, the curves are obtained by sections of surfaces filed in the tridimensional data base. He can easily manipulate the geometrical figures through translations, rotations, symmetries or scale changes. Rotation is semiautomatic. Numerous analysis functions are available: computation of perimeter, area, volume, inertia, etc. A specialized function automatically determines the flat contour of the sheet metal parts.

The designer also benefits from an interesting extension towards tridimensional applications: he may create ruled or plane surfaces which are particularly well suited to definition of wings, frames or ribs. They are usually computed automatically by optimal schematization of the complex shapes on which the wings of the part he draws come to bear.

4.3. Manufacture

In its third function, the DRAPO system is the tool for preparation of NC machining of the geometrical elements filed in the data bank.

The NC programmer uses the interactive graphic console to describe the path of the milling cutter or selects the geometrical figures in which the cutter is to bear. He also defines the shape of the tool (spherical, annular, cylindrical), the type of machining (3- or 5-axis) and the necessary technological data.

Constant machining monitoring by display and animation of the milling cutter on the screen, allows the NC programmer to avoid any errors and, if need be, correct the geometry of the part in order to best adapt it to the manufacturing techniques.

This is the way in which the wind-tunnel models, the integral structural parts and most tooling items are machined.

V. Implementation of the DRAPO System

Some three hundred engineers and technicians use the DRAPO system in the company's six plants every day.

They frequently obtain sections from any drawings whatsoever and plot projections and cylindrical or conical perspective drawings from the shapes filed in the data bank. Two examples serve to illustrate this application on a military plane (figure 8) and a civil aviation plane (figure 9).

Figure 10 is a front view of the main frame for a military plane; figure 11 is a perspective drawing of a structural element; figure 12 is a kinematic working drawing of an undercarriage. Figure 13 is an electric circuit diagram. Each component is represented by a symbol filed in a special library managed by the user.

VI. Prospects

The developments in new applications are not lacking and some are being developed, especially in the areas of data bases, geometry (operations on solids, automatic gridwork) and mechanics (complex kinematics studies).

But our major concern involves the hardware.

a) Consoles

The quality of present-day consoles is acceptable for bidimensional processing. However, the introduction of colour and the increase in resolution and the number of vectors displayed are necessary progressions which have already been achieved by some console manufacturers.

Our experience has shown us that other indispensable stages will have to be passed through to achieve wide-spread use of tridimensional applications.

In a first stage, a local processor offered by some manufacturers allows real-time processing using new means of dialogue: rotations and translations (on a plane and in space), scale changes. The data transmitted to the terminal are lists of points (X, Y, Z). In addition to the effective aid it affords the operator, this technique simplifies development of applications and relieves the computer of more than 25% of the computations.

In a second stage, the computer should transmit lists of curves to the graphic terminal in the form of standardized polynomial equations. A local processor would compute the projection of each curve of the picture in a plane and would discretionalize it into a list of points (X, Y) whose number and distribution would depend on the development of the curvatures and the scale determined by the operator.

In a third stage, it would be necessary to set up a new display technology. Indeed, the mode of representing surfaces and solids will remain quite imperfect on jumper-scan graphic display screen; high-resolution video scanning (over 1000 lines), for example, would be much better suited. The computer would transmit to the terminal lists of faces (cf. section 3.1.c) whose mathematical representation would have been standardized beforehand. The local processor would display them, eliminate the hidden parts and, naturally, enable real-time translations, rotations and scale changes.

It is only at this level of technology that consideration can be given to massive use of computer-assisted design and manufacture in the tridimensional field.

b) Computers

Widening of the fields of application will require a reduction in the processing time. But, numerous examples (such as the section of a solid by a plane) clearly show that a large number of computations could be performed in parallel. Therefore, we hope to see a new generation of computers whose architecture would be adapted to parallel computations.

Conclusion

The balance sheet for use of the DRAPO system over the last twelve years has proved to be quite positive for the AMD-BA company.

Despite the enormous efforts exerted, and perhaps owing to the benefits and advantages acquired, we are convinced that we are only at the start of implementation of Computer-Assisted Design and Manufacture in our design offices and workshops. It appears that, in the future, development of the DRAPO system can only be all the more accentuated in order to adapt it to the new requirements and new techniques of aeronautical construction.

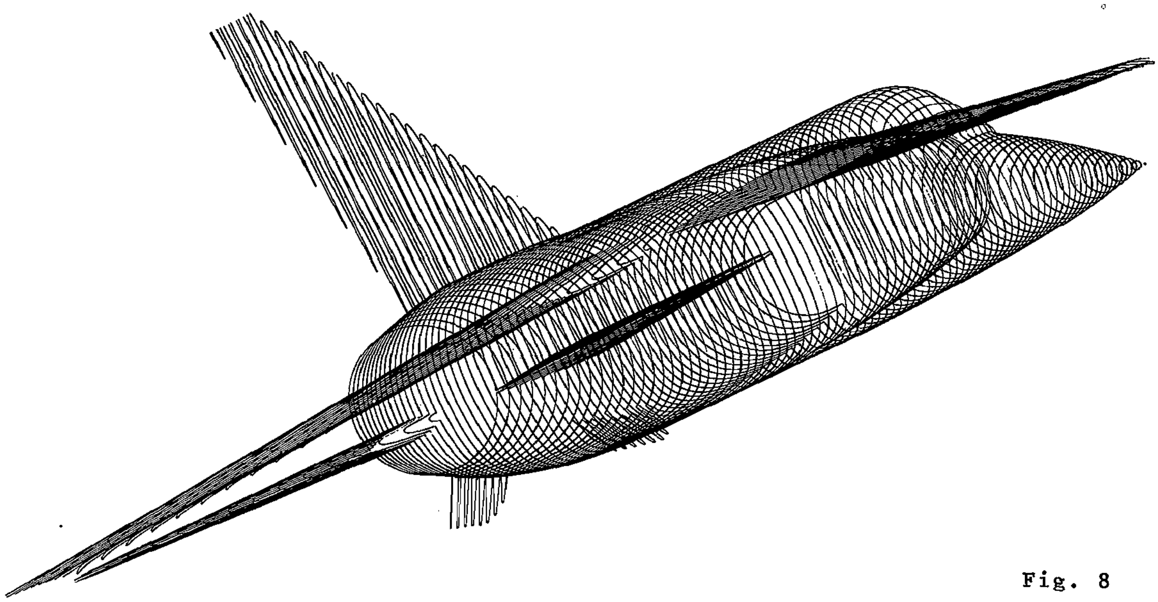
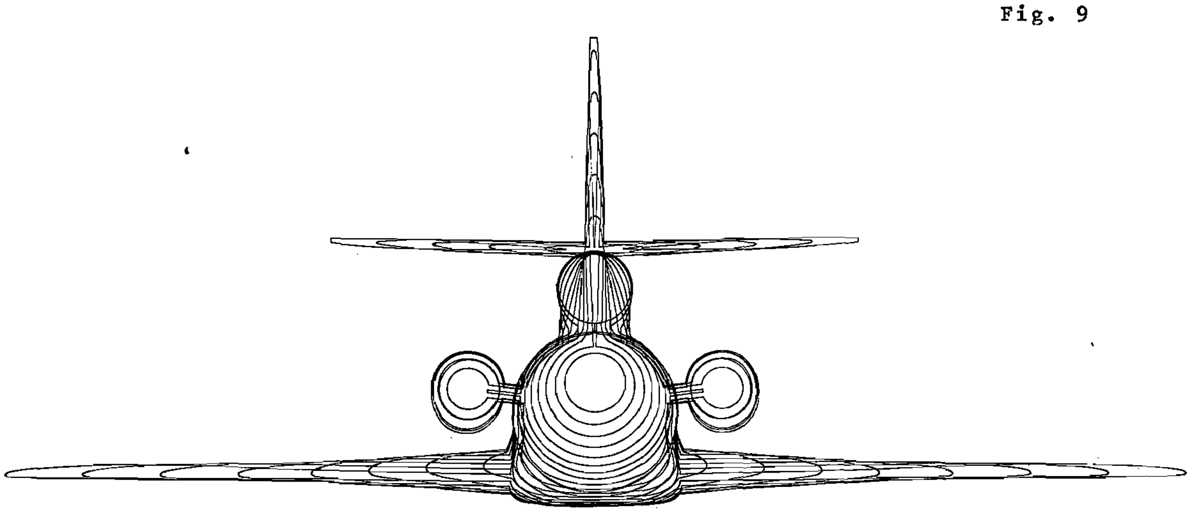


Fig. 8

Fig. 9



DRAPO

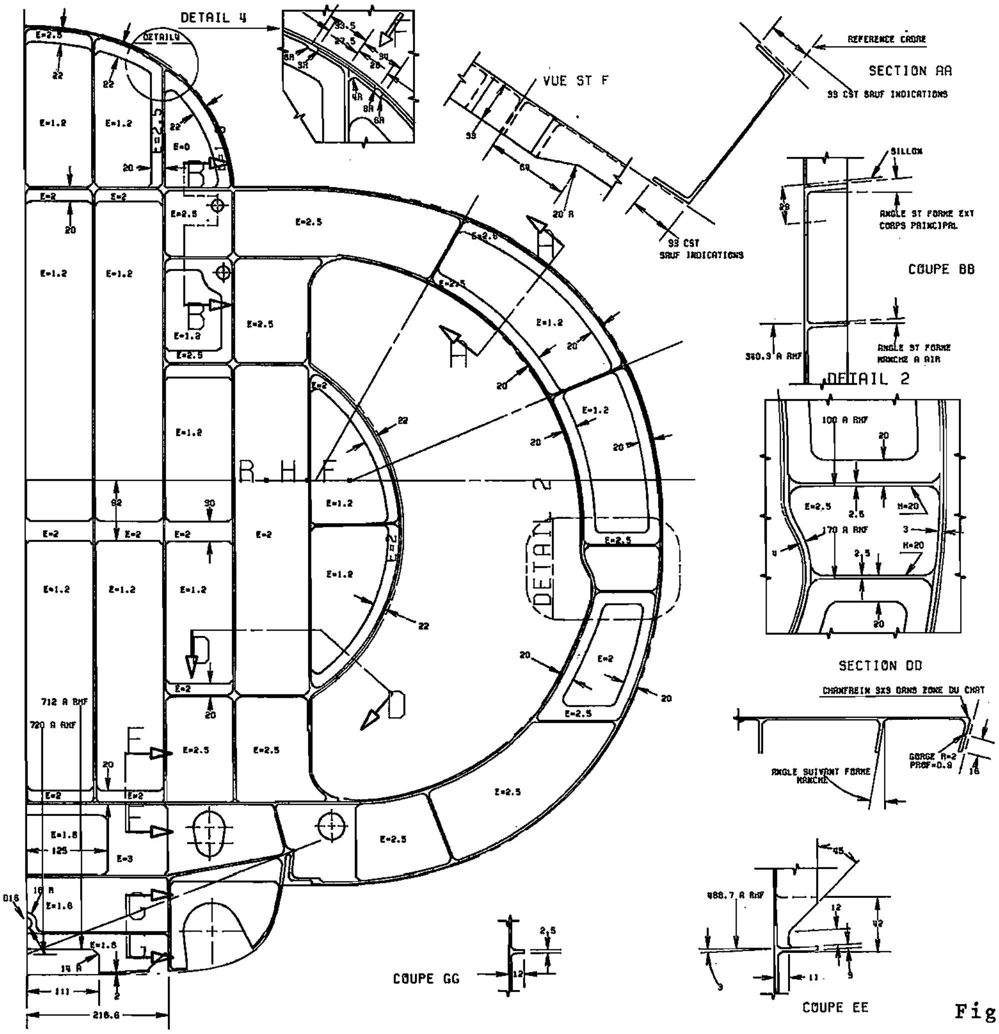


Fig. 10

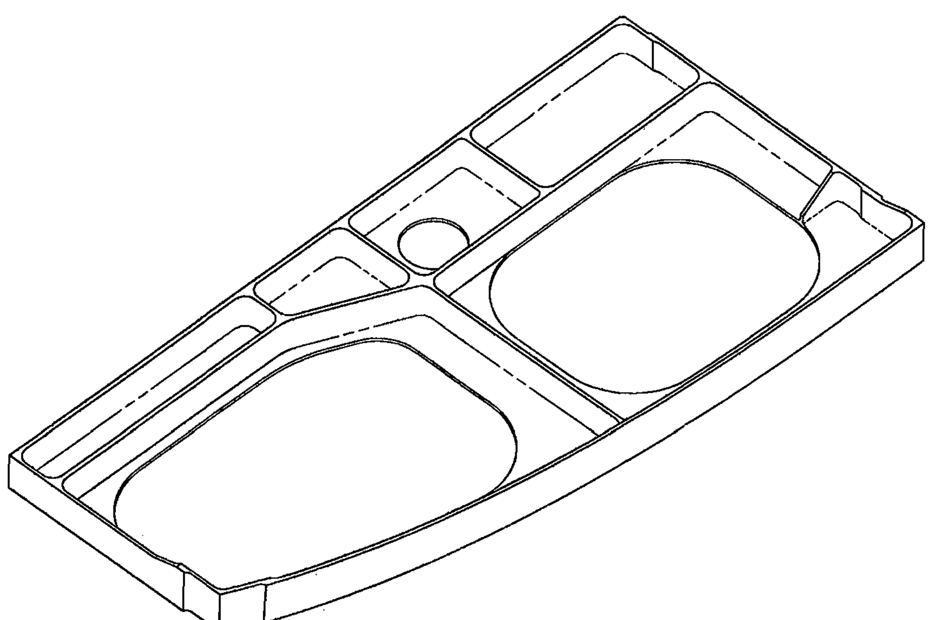


Fig. 11

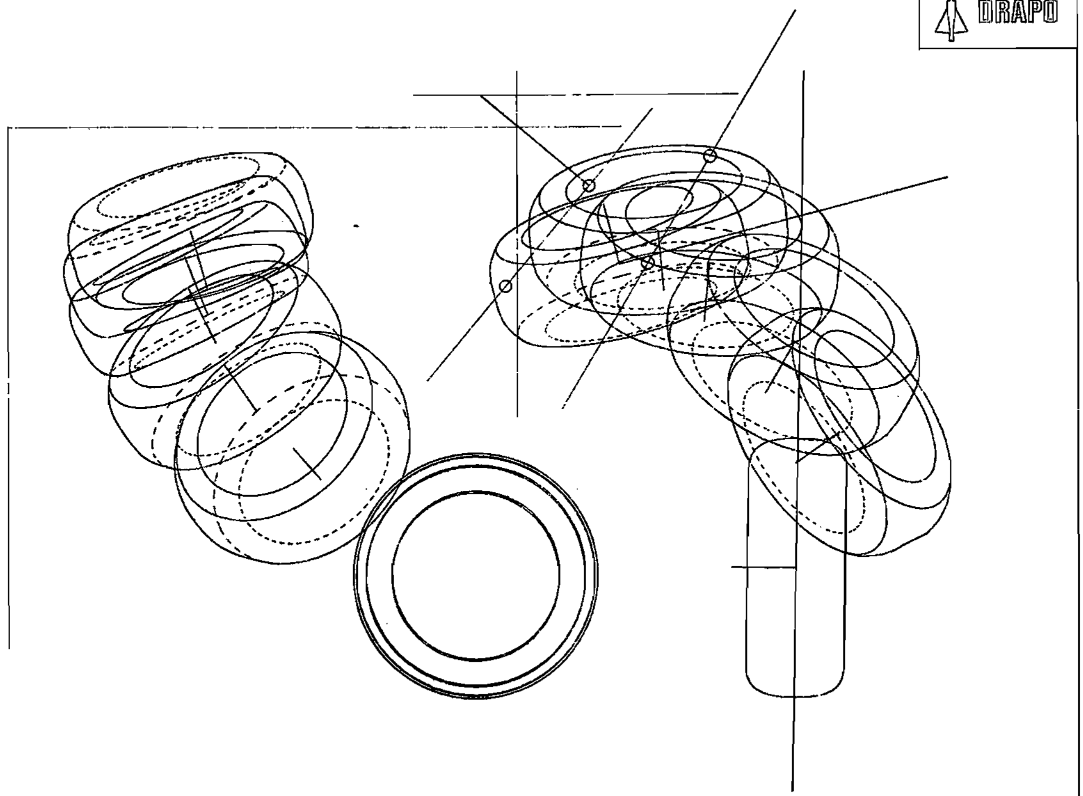


Fig. 12

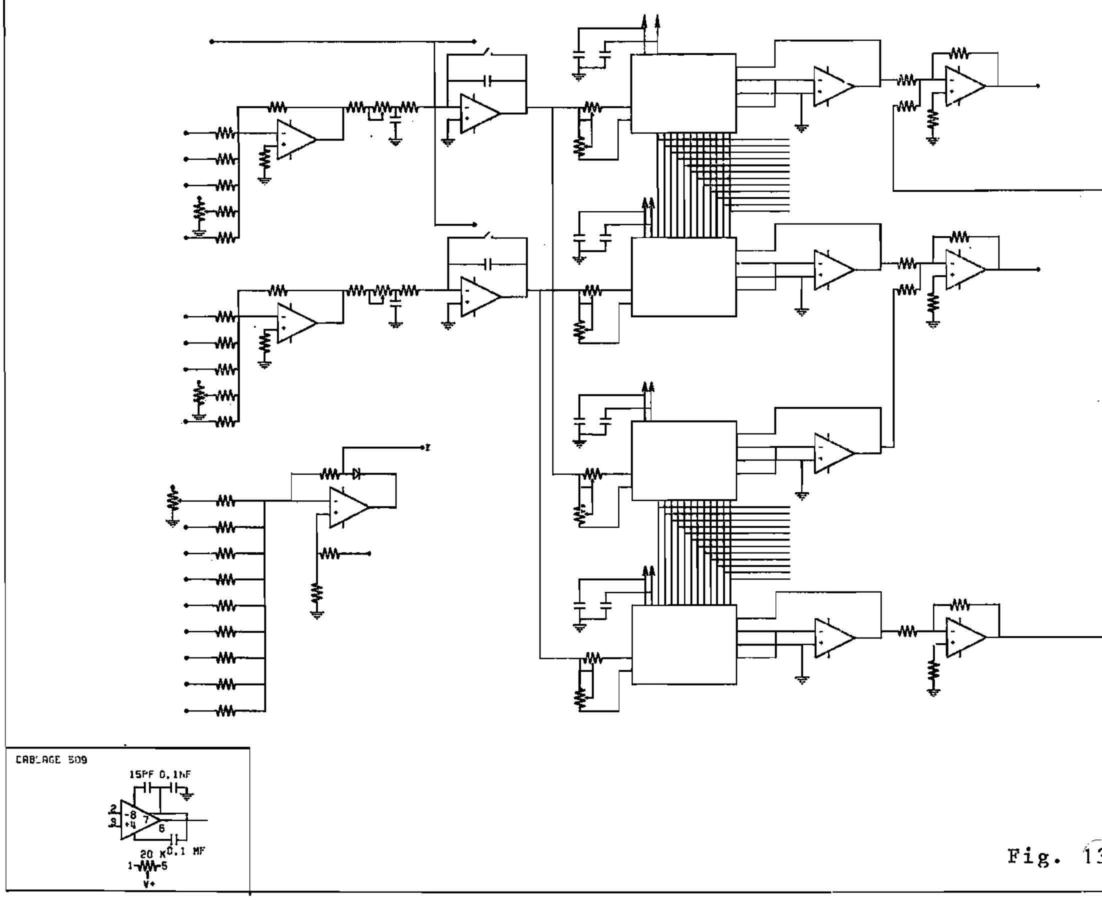


Fig. 13