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## Computer Aid in the Production Design Office

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- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

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## PREFACE

A Specialists' Meeting on "Computer Aid in the Production Design Office" was held in Florence, on 25th and 26th September 1978, under the sponsorship of the Structures and Materials Panel during the 47th Panel Meeting. The Meeting was divided into three sessions, the first being concerned with "Present Technical Possibilities", the second devoted to "Applications in Design Offices", whereas the third session comprised a general discussion on the topic and a review of Sessions I and II.

The Specialists' Meeting was a direct follow-on activity of the pilot papers delivered to the Sub-Committee at the Fall 1977 Panel Meeting. As one of the pilot papers already gave a detailed impression of the situation in the USA, this Specialists' Meeting was tailored to clear the state of the art in the European aerospace companies.

The papers presented in Session I gave a survey on "Present Technical Possibilities", addressing the requirements with respect to soft- and hardware from different points of view as well as the close relationship between CAD and CAM. One link between CAD and CAM is formed by a Common or General Data Base, while another one evolves when looking for the benefits following the introduction of such systems: Even if costs in the design office are equal to or higher than those following conventional procedures - especially during introductory phases - the savings in costs and lead times result from manufacturing.

The "Applications in Design Offices" in Session II covered the application of CAD to special systems and components of an aircraft. The sometimes competitive needs of different branches of the design offices and manufacturing were pointed out as they ask for well balanced compromises in defining soft- and hardware modules. During introductory phases the inertia of existing organisation must not be underestimated, and due care should be given to training of staff and human aspects of interactive work with the computer by means of screens and keyboards.

The Specialists' Meeting has been a success, not only by the quality of the papers presented, but even more by bringing together the specialists in this field of the Member Nations for lively discussions. With respect to multi-national development and manufacturing programmes a need for interfaces between the different CAD and CAM-systems within companies involved showed up. Hopefully the Specialists' Meeting brought about the personal contacts needed for future cooperation into this direction.

R.J. MEYER-JENS  
Chairman, Sub-Committee  
on Computer Aided Design

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Graphical NC Systems as a Basis for  
Progress towards the Integration of  
Design, Planning and Machining

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SUMMARY

The Computer Aided Design Centre, Cambridge, England, has been concerned for the past 9 years with the provision of computer software to promote the introduction of computer aided design and manufacture throughout all sectors of industry. The CAD Centre is dealing, in the main, with small companies, many of which are subcontractors to the aircraft industries. From the outset, the integrated approach was considered to be essential - in other words, design and production had to be considered together as part of the total manufacturing process if the full effectiveness of computer aids was to be achieved. Ideally, the engineering product would be represented by a model which would be defined, modified and used in common by designers, planners and production engineers. In practice, of course, such a concept could not be achieved in one step; this paper describes the pragmatic evolution of several computer systems moving towards the ideal, based initially on graphical n.c. part programming. This was the logical starting point for the developments since:

- (a) n.c. programming aids are in great demand in order to maximise the economic utilisation of n.c. tools;
- (b) all the problems of geometric part description which exist at the design stage must be solved also at the n.c. programming stage;
- (c) by basing design and draughting software on a pre-existing n.c. programming system the utilisation of n.c. machining methods would be favoured, leading to further improvements in overall manufacturing economics.

The systems to be described are all concerned with engineering piece part components as distinct from assemblies of components. We are dealing with the design and machining - by any n.c. controlled method - of such components and the estimating and process planning which goes with their manufacture.

The systems produced to date, and which are now in quite widespread use through a number of agents, include modules for 2½-dimensional part machining; 3-dimensional surface fitting and machining; and a "families of parts" description language which allows a designer, planner or estimator to create a part description extremely rapidly, for subsequent re-processing into drawings, n.c. tapes, cost estimates or process planning sheets. The systems provide facilities for all machining and profile cutting methods, the graphics being a particularly powerful aid for n.c. turning in dealing with tool and workpiece clash avoidance.

Current work is concerned with two developments. Interactive parts drawing and dimensioning facilities are being added while the system as a whole is being interfaced to a suite of process planning software which is commercially available and has gained considerable acceptance in the United Kingdom. The result is expected to be a powerful and comprehensive "design to manufacture" system for machined parts, including dies and moulds, the elements of the system being applicable, of course, to any profile or surface cutting requirement.

INTRODUCTION

1. The CAD Centre is a government financed development organisation which aims to increase the use of computer aided engineering methods in industry. Where possible it obtains software and techniques from research organisations and works to produce programs which are fully supported and in a marketable condition. Experience has shown, however, that major advances in software systems are made only over a considerable period of years through close collaboration with the potential engineering users and with development teams in industry, where they exist. The Centre has to provide systems suitable for small, as well as large, companies and for this reason has tended to view the aircraft industry as a source of software and methods rather than as a potential customer. Nevertheless, the results are of relevance to the industry itself and are now in use by a number of companies who are sub contractors to the larger aircraft firms.



2. The systems described in this paper are concerned primarily with piece parts with an emphasis on production and design for production, rather than the original or "creative" aspects of design. Developments first began in 1971 and, from the outset, the integrated approach was believed to be essential; in other words, the activities of design and production had to be considered in an overall context if the benefit of computer aids were to be maximised. These aids would be fully effective only when designers and production engineers could define, visualise and store within the computer a common product description which could be modified as required and from which output could be produced in the form of drawings, estimates, planning sheets and machining instructions. In practice, of course, such a concept could not be achieved in one step, especially since the Centre's mode of operation meant organising collaborative development projects with industrial companies which, in the main, have immediate problems to solve. Although fully integrated systems can be seen to offer great benefits there are many practical obstacles to their rapid introduction, among which are technical complexity, long time scales, meaning delayed payback and more risk, and increased human problems arising from the compressing of job functions. A pragmatic approach was therefore adopted, involving the evolution of several CAD systems which could later be integrated, starting initially with n.c. part programming. Although developments in three dimensional surface geometry and n.c. machining were already underway at this time and are now in regular use this account will concentrate rather more on the "2½-dimensional" systems for common piece parts produced by profiling methods, 3-axis milling and n.c. turning, since these are of more widespread application.

#### OBJECTIVES

4. In 1971 it was argued as follows.
- (a) n.c. machining would become common throughout industry during the next few years as skilled manpower became scarcer and machine tools became cheaper under the impact of improved technology and the influence of imports from (e.g.) Japan;
  - (b) when this happened n.c. part programming would become a bottleneck. Industry would require low cost means of part programming reliably and quickly, leading to a demand for interactive graphical methods;
  - (c) no existing systems offered the required facilities at the right price for most small companies. However, over the time scale envisaged (about 5 years) it was anticipated that low cost mini-computers would provide the basis for such systems if the software were available and could be adapted to a variety of machines;
  - (d) the introduction of n.c. machining and computer aided n.c. programming would have a greater effect on overall manufacturing economics than, say, computer aided draughting, while forming a suitable "spring board" for the later addition of component draughting, estimating and planning.
5. These arguments have been confirmed by events. The U.K. now has a higher proportion of n.c. machines in its workshops than any other country excepting U.S.A. and Japan, and the demand for effective programming aids is rising rapidly at the present time. The largest proportion of these machines are lathes, as would be expected, since about 80% of finished piece parts are predominantly turned. With the wider acceptance of computers generally in production engineering the opportunities for further integration are now seen clearly by many more engineering firms. Moreover, computer aided process planning systems are also becoming available on mini-computers, based on modular software which can be adapted to a wide variety of companies' requirements.

#### SYSTEM DESIGN CRITERIA

6. With the previously defined objectives in mind, and especially in the likelihood of continual modification and integration with new system modules, the following basic design criteria were adopted.
- (a) all systems written in ANS1 standard Fortran;
  - (b) systems to require only standard manufacturers' hardware;
  - (c) interactive graphics using Tektronix storage tubes; hence keyboard oriented language input for efficiency and low cost;
  - (d) non-interactive data input used where suitable to minimise operating costs (man and machine);
  - (e) system modules chosen to match the functional divisions encountered in industry, so allowing a natural evolution towards increased integration;
  - (f) data structures within modules chosen for speed of response and low

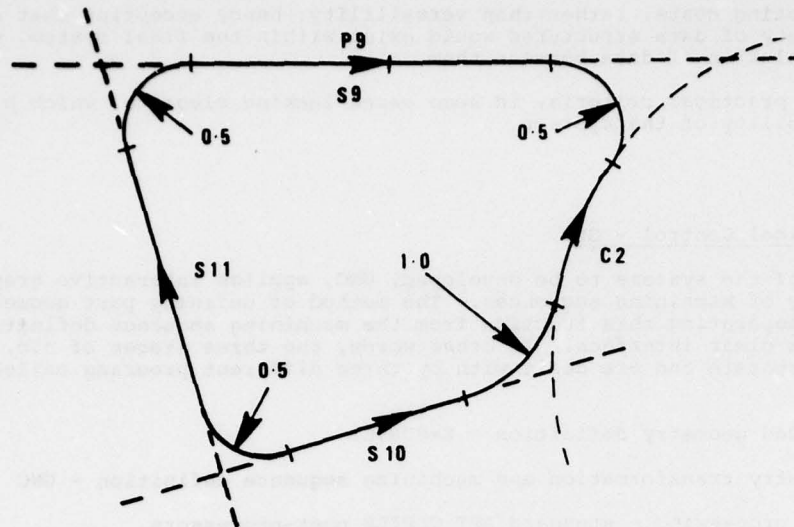
operating costs, rather than versailility, hence accepting that a variety of data structures would exist within the final system, with translation of data between them.

These were practical criteria, in some cases lacking elegance, which have ensured the adaptability of the systems.

#### CURRENT SYSTEMS

##### Graphical Numerical Control - GNC

7. The first of the systems to be developed, GNC, applies interactive graphics to the programming of machining sequences. The method of defining part geometry was left "open" by separating this function from the machining sequence definition and providing a clear interface. In other words, the three stages of n.c. processing are kept separate and are dealt with by three different programs called up by the user:-
  - (i) bounded geometry definition - K-CURVES
  - (ii) geometry transformation and machining sequence definition - GNC
  - (iii) post processing - standard APT CLFILE post-processors.
8. The definition of bounded geometry is carried out by a non-interactive program which describes 2D composite curves using all the usual points, lines and circle definitions and constructions. The processed geometry may be viewed at the graphics terminal and any shape errors noted. The user can then edit his geometry data file to correct illegal geometry definitions, syntax errors or make shape changes. The geometry program may then be re-run and the cycle repeated until the geometry is correct.
9. Only when the user is completely satisfied that the geometry is error free will he define any machining sequences, by starting the second program. GNC is a graphical interactive program which accepts the geometric description of the curves output from the K-curves program. GNC is organised into a system of module options:
  - (a) GNC Root module;
  - (b) Shape nesting option;
  - (c) Curve fitting option;
  - (d) Milling sequence option;
  - (e) Lathe sequence option;
  - (f) Plotting sequence option.
10. The sequence definition modules enable cutter movements to be specified in relation to the predefined geometry by use of a simple command language and the cursor facilities of the Tektronix terminal. The GNC user need not refer directly to component dimensions or to geometry elements less than complete K-curves. The supplementary information required on the final control tape is also specified at this stage and is finally processed with the cutter paths to produce an APT compatible CLFILE. Post processing and tape production (program (iii)) is a routine batch processing task. Since the user has had the opportunity to check and correct the geometry at an early stage, and has specified and animated the tool path graphically, few errors should now exist. If modifications are required at a later date to the geometry or machining sequences, then by retaining the simple intermediate data files (kept in readable character form) the programs (i) and (ii) may be re-entered readily and new control tapes produced.
11. The keyboard language is as terse as possible, for maximum user efficiency when working at a terminal. The program which is used to define bounded geometry is an adaptation of one originally developed by the British Aircraft Corporation, Weybridge. The bounded geometry for turned parts can be generated automatically from "family of parts" programs. The K-CURVES module uses an extended version of the economical PROFILEDATA geometry language to define basic points lines and circles and adopts a similar syntax for defining bounded profiles. An example of a statement defining a close profile, named "K8" is given in Figure 1. Note the modal value of the 0.5 fillet radius at the beginning of the line.
12. Program (ii) - the GNC module - has extensive facilities for viewing all, or parts of, the defined geometry and would normally be used at this stage to check the profiles visually. The K-curves may also require re-orientation or repeating to suit the position of components in the co-ordinate axes of the machine tool. After reading the K-curves character file all subsequent GNC commands and data are entered interactively, or by adding to the existing input file using a text editor. The GNC command language consists of single command words followed by a variable number of free-format numeric arguments, depending on the command. Each command may



K8 R0.5 P9 TS9 CF NAC 2 CF 1.0 NAS 10 CF TS11 CF TS9 P9 EK

Figure 1

be abbreviated to its first three characters. The system responds to each command before the next is given.

13. The GNC system is simple to use, the language currently containing about 140 commands. Seven groups of commands cover basic facilities:

- (i) database utilities
- (ii) general utilities
- (iii) geometry definition
- (iv) geometry transformation
- (v) picture control and display
- (vi) sequence editing and filing
- (vii) tooling definition

and five other groups cover optional facilities:

- (viii) curve fitting
- (ix) shape layout and nesting
- (x) stored "milling" sequences, covering also drilling, nibbling and flame cutting
- (xi) stored lathe sequences
- (xii) stored plotting sequences

14. It is not the purpose here to give detailed descriptions of the GNC system. However, the lathe machining sequence is interesting as the graphical interactive facilities are particularly useful for collision checking. In addition to the component geometry database the user can create an alphanumeric toolfile and also relate pre-defined K-curves to the four lathe tooling elements, namely:-

TURRET  
TOOL  
TOOL-HOLDER  
FIXTURE

The appropriate commands allow these elements to be associated with their profiles for visual reference and collision checking. The TURRET/command, for instance, carries up to 12 arguments, defining its name, the number of tooling stations, the number of turret faces, the translation axes, the turret type, turret axis

inclination, the rapid feedrate value, an identifier for the post-processor and limits for the turret centre motion.

15. Before creating a lathe sequence, the part-programmer must decide on what tooling he is going to use for the job in hand. This may be done by referring to the GNC toolfile catalogue. If the lathe installation accommodates multiple tooling positions, each tool station may be allocated a tool, and tool holder. Pre-set tooling offsets may be stored in the toolfile but may be overruled at this stage if required. From this stage, each tool is referenced by tool station only. The part-programmer is thus relieved of the tedious task of accounting for tooling offsets, whilst programming motion statements. As in milling sequence mode, a small area at the top of the display screen is devoted to displaying machining parameters. Figure 2 illustrates a typical screen view showing an outline of the material stock, the required component profile and the turret, tool holders and tools in a particular orientation.

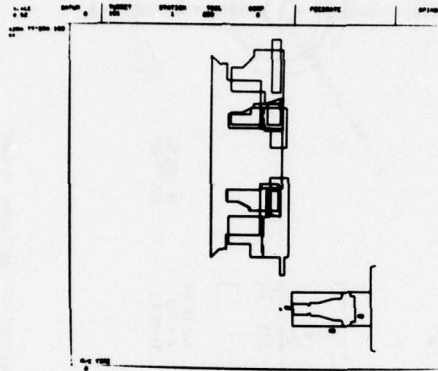


Figure 2

16. The cursor facilities of the storage tube terminal are used to supplement the keyboard language in several instances. In milling sequence mode the command LINEMILL/ activates the cursor and the co-ordinates of the current cursor position are returned to the program when a single keyboard character is depressed. Various functions are available, "A", for instance, causing the cutter to move to the position indicated by the cursor. The cutter path is shown by dashed lines - short distances for feedrate moves, long for rapid moves. The cutter can also be made to "attach" itself to the nearest point on a nearby profile. A manual control of the tool position can be achieved using the GOZX/ command together with single characters which control the direction and speed of the tool motion.
17. A major feature of GNC is that machining sequences may be edited and animated during the interactive session. A sequence may be restarted, a specified command located and new commands inserted at the current position. When exit from GNC is made the sequences are reprocessed in numerical order to produce a CLFILE.

#### TURNED PART ENGINEERING - TPE

18. Turned parts exhibit a limited number of common features. It therefore becomes possible to define such parts in terms of their features, dimensions, material and surface finish, using a manageable number of keywords. TPE provides such a keyword language for components such as shafts, gears, bushes, cylinders and wheels. It has been used as part of a cost estimating system and as a "pre-processor" for GNC to generate bounded geometry for turned parts. The language is oriented towards detailed operations planning, its interactive features enabling existing estimators and planners to use it with very little training. It also offers the possibility of reducing the need for component details drawings. A typical part is illustrated in Figure 3.
19. The machining sequence planning aspects of the TPE and GNC programs are complementary although TPE is applicable to conventional machine tools as well as to n.c. machining. Whereas GNC provides animation facilities allowing the part programmer to simulate the most complex machining sequences, after the part geometry has been defined, TPE generates the part geometry as an integral part of the machining operations planning. This approach is clearly of fundamental importance and work



is proceeding to apply it to other than turned parts. The geometry of a finished part is the end product of a sequence of machining operations. By using a language based on machining operations the user need not be concerned explicitly with details of geometry although, of course, he will be specifying the dimensions of the component's features. The example in Appendix 1 gives the flavour of TPE.

#### PROCESS PLANNING

20. Having developed modules for n.c. machining and piece part description the next phase is to link them with process planning software to begin to provide the possibility of an integrated piece part manufacturing system. Appropriate methods of describing complex parts (volume modelling) are not yet available, but since we can now handle the geometry of flat parts and turned parts the focus has turned to integration for these classes of parts.
21. Bearing in mind our emphasis on the smaller companies, the use of mini computers and collaborative effort as the most efficient method of development, the Centre has recently made arrangements to link its programs with PCPROP, a comprehensive suite of process planning software which has been under development for a number of years by a British consultancy company, Logan Associates. PCPROP is a high level language which enables an industrial engineer to state his problems in a natural manner and obtain detailed manufacturing instructions based on the collated experience of his own company, set up in a technical data base. The system has been reimplemented on a number of mini computers, including the Nova 3/D, GEC 4070 and the PRIME 300/400 series.
22. At present PCPROP comprises three major sub-systems:-
- ROTARY - general purpose machining program
  - MANTI - a manual times program based on Methods-Time Measurement
  - MULREG - a multiple regression program

All are written in FORTRAN IV. The data base includes a company's own time and methods standards but there is also available a comprehensive and accurate set of synthetic times data, derived originally from the extensive manuals developed by the Mecford company of Naples. By the use of multiple regression techniques together with macro facilities, planning data is manipulated at various levels. The formulae and operations weightings which determine the time for a low level task may be synthesised into higher level formulae, each embracing a larger field of activities.

23. The previously separate operations of piece part detailing, operations planning and cost estimating can now be collapsed into one operation if this is required. At the very least the same data base is utilised by the separate operations, and detailed drawings can be produced semi automatically, with interactive drawing facilities used essentially in a tidying up mode. Geometry can be transferred automatically for n.c. programming. Although such an approach is suited only to topologically simple machined parts, these nevertheless comprise a large percentage of parts made and, as geometric modelling methods are improved, the approach can be extended. For overall manufacturing efficiency it is clearly important to persist in the notion that machined parts are, fundamentally, the end result of a set of machining motions, and to try to minimise the superfluous drawing effort that is currently consumed in the conventional activity of detailing.

APPENDIX IExample of Part Definition using TPERaw Material Type?

817M4Ø

Raw Material Form and O/a Dimensions?

FORGING 115 (32+94+34+6)

No forging dimensions are shown on the drawing, so allow 6mm on diameter and length

Raw Material Feature?

DIAMETER 42 32

Diameter at l.h. end (6mm up on finished size)

DATUM DIAMETER 51 4

Move datum to end of last diameter, define next diameter

DATUM 200

Move datum to r.h. end (200 takes it beyond the end, but it will be pulled back to the end)

DIAMETER 51 -94

These diameters all have negative lengths

DIAMETER 42 -34

because they extend back (leftwards) from

DIAMETER 34 -18

the current datum

END

End of raw material from definition

Finished Features?

FACE 3

Face at l.h. end (datum is reset at  $x = \emptyset$  automatically)

DIAMETER

Diameter for thread

CHAMFER 2

Chamfer at l.h. end: default angle is 45 degrees

DATUM PRO GROOVE 2 -2

Move datum to end of diameter, do profiled (radiused groove)

THREAD 2 -14 -2

Thread starts 2mm back (left) from current datum

DIAMETER 36 16

Define next diameter

GRIND

Grinding operation assumed because of accuracy required

CHAMFER 2 Ø 3Ø

Chamfer at current datum: angle of 30 degrees must be given

UN SYSTEME DE CONCEPTION ET FABRICATION ASSISTEES  
PAR ORDINATEUR ADAPTE A LA CONCEPTION DES  
OBJETS TRIDIMENSIONNELS

par

Monique SLISSA

Ingénieur Civil de l'Aéronautique

AEROSPATIALE

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13 722 - MARIIGNANE

RESUME

La Conception et la Fabrication Assistées par Ordinateur regroupent toutes les utilisations de l'ordinateur pour créer un produit à moindre coût, aussi rapidement que possible et pouvoir le modifier dans les délais les plus brefs.

Le domaine d'application choisi par la division Hélicoptères de l'Aérospatiale est celui de la conception des objets tridimensionnels.

Un programme, développé au sein du Service Informatique Scientifique, mis en exploitation dans l'entreprise dès 1974, permet la création et la modification conversationnelles, l'exploitation (traçage, usinage) de n'importe quelle forme à l'aide d'écrans graphiques et alphanumériques.

Le développement se poursuit pour tenir compte de l'expérience acquise auprès des utilisateurs ; des comparaisons favorables ont été faites avec les méthodes traditionnelles.

Pour rationaliser la gestion des objets créés, l'introduction d'un système de gestion de base de données de type nouveau est en cours d'étude.

1 - INTRODUCTION :

La Conception et la Fabrication Assistées par Ordinateur regroupent toutes les utilisations de l'ordinateur pour créer un produit déterminé à moindre coût, aussi rapidement que possible et pouvoir le modifier dans les délais les plus brefs.

Ces techniques recouvrent plusieurs domaines : la création des données qui décrivent l'objet à concevoir, la manipulation de ces données, afin d'aboutir à une forme achevée de conception. Elles comportent aussi la génération des informations nécessaires à la fabrication de cet objet à partir des données de description de la conception, stockées dans l'ordinateur. C'est également la mise en oeuvre de techniques interactives, graphiques et alphanumériques, pour supporter les dialogues homme-machine dans le processus de création.

Les domaines dans lesquels ces techniques sont appliquées à l'Aérospatiale Marignane, à l'heure actuelle, montrent des gains suffisamment importants (gains en coût supérieurs à 25 %, gains en délais supérieurs à 50 %) pour justifier l'extension des méthodes de Conception et Fabrication Assistées par Ordinateur dans l'entreprise.

2 - PHILOSOPHIE DE LA CONCEPTION ET LA FABRICATION ASSISTEES PAR ORDINATEUR A MARIIGNANE :

Le but vers lequel tendent les études et les développements en cours dans la Division Hélicoptères de l'Aérospatiale, à Marignane, consiste en la réalisation d'un système intégré de Conception et de Fabrication Assistées par Ordinateur, c'est à dire une aide continue de l'informatique depuis le cahier des charges jusqu'à la fabrication du produit Hélicoptère.

Il est à noter que l'effectif de la Division Hélicoptères de l'Aérospatiale est d'environ 7800 personnes, ce qui en fait le deuxième Hélicoptériste du monde Occidental. Son chiffre d'affaires pour 1977 a été de l'ordre de 2400 millions de francs français et le nombre cumulé d'hélicoptères vendus a atteint 5100 dans 95 pays.

Dans une entreprise de cette importance et fabricant des produits demandant un haut niveau de qualité, les raisons d'utiliser des méthodes de Conception et de Fabrication Assistées par Ordinateur sont nombreuses.

En évitant la redescription d'un produit chaque fois que l'on change de technique (Etudes, Fabrication, Gestion...) ou en la réalisant automatiquement, ou en rendant les diverses techniques compatibles, l'on diminue les cycles de production, en réduisant aussi les risques de conflits.

En faisant accepter l'outil informatique par les techniciens, soucieux, à juste titre, de conserver leur méthodologie, en leur fournissant un poste de travail adapté, l'on peut obtenir des cycles plus courts. En particulier, l'aide au concepteur peut être très efficace lorsque la tâche de conception consiste en un assemblage de productions algorithmiques (par exemple forme parallèle à une autre forme,



forme développable...). Il est possible, aussi, de balayer des cas marginaux trop nombreux pour être traités de manière traditionnelle ou nécessitant auparavant une mise en oeuvre trop longue.

### 3 - CHOIX D'UN DOMAINE D'APPLICATION

Le début des études dans le domaine de la Conception et la Fabrication Assistées par Ordinateur, à Marignane, date de janvier 1972.

Après enquête dans le Bureau d'Etudes pour définir les domaines d'application se prêtant à la mise en oeuvre de telles méthodes, et étude des prolongements possibles en fabrication, des objectifs ont pu être établis et des choix déterminés. Le domaine d'application retenu en premier lieu a été celui de la conception des objets tridimensionnels.

C'était un domaine peu connu, posant dans l'industrie des Hélicoptères des problèmes assez voisins de ceux de l'industrie automobile. Il a de grandes et nombreuses ramifications dans tous les autres domaines (équipements, motorisation...) C'est aussi un domaine où l'interactivité permet le choix de la solution en temps réel (contrairement au calcul des structures par exemple). C'est enfin un domaine éminemment créatif.

### 4 - DEVELOPPEMENT DU PROJET

Il peut être décomposé en plusieurs phases :

- (a) La phase de démarrage s'étendant sur l'année 1972, a constitué en une étude de faisabilité, débouchant sur le choix d'une technique et d'un support.
- (b) La phase suivante, s'étendant sur les années 1973 et 1974 a vu la priorité donnée à l'aspect mathématique. Il y a eu également, au cours de cette période, apparition des tâches de "marketing" au sein de l'entreprise.
- (c) Une troisième phase a consisté en la mise en exploitation du système ; une partie de l'équipe de développement a été alors chargée de former les utilisateurs de divers services de l'entreprise, de les aider dans leurs débuts, de promouvoir le système et aussi de faire office de "capteur d'information", afin de pouvoir l'adapter aux désirs des utilisateurs. C'est grâce à ces retours d'informations que de nombreuses évolutions ont été possibles, très enrichissantes pour le système.

### 5 - ACTUELLEMENT

- (a) Le système maintenu et développé par une équipe du Service Informatique Scientifique, au sein du Bureau d'Etudes, est exploité par les services d'Etudes et de Fabrication dans l'entreprise. Les utilisateurs sont, selon les problèmes traités, des ingénieurs de haut niveau, des projecteurs, des dessinateurs, des traceurs et des programmeurs de machines-outils à commande numérique.
- (b) Le système permet de créer et de modifier de manière conversationnelle n'importe quelle forme simple ou complexe à l'aide d'écrans graphiques interactifs et alphanumériques. Il offre également la facilité d'exploiter les formes créées : tracés à l'échelle désirée sur divers supports (en particulier carte à graver sur fil polyester, stable dans le temps), définition d'outillages de fabrication à partir des formes théoriques créées, génération des bandes d'usinage pour machines à commande numérique.
- (c) Concepts de base :

Sans entrer dans des détails théoriques, les concepts de base du système peuvent être résumés ainsi : les courbes et les surfaces ont une représentation unique, paramétrique polynomiale, ce qui assure la notion d'objet tridimensionnel ; le système, qui ne connaît donc qu'un seul type d'entité est de plus de type automate, tout cela lui conférant une maintenance aisée et une grande souplesse d'évolution. Les programmes sont écrits en langage Fortran, synonyme d'une certaine transportabilité.

- (d) Le matériel mis en jeu comporte :

- un ordinateur I.B.M 370 158 de 2500 K qui supporte l'ensemble des travaux de Bureau d'Etudes.
- trois écrans graphiques interactifs I.B.M 2250 modèle 3, deux au Bureau d'Etudes dont un au Service Informatique Scientifique, et un au Service Tracage
- des écrans alphanumériques (I.B.M 3277 et TELEX TC 277)
- un traceur Benson
- un digitaliseur Benson
- une machine à tracer Kongsberg (6 m X 1,6 m)
- un parc de 70 machines-outils à commande numérique.

### 6 - LES FONCTIONS DISPONIBLES

Le système se compose d'une part d'un ensemble de programmes permettant la conception interactive d'objets tridimensionnels, d'autre part de programmes d'exploitation pour la sortie des tracés et la génération des bandes pour l'usinage en commande numérique.

Les fonctions offertes peuvent être ainsi classées :

- 1) Les fonctions de création de courbes et de surfaces, de reproduction (lissage avec ou sans contraintes ponctuelles et tangentielles), de raccordement d'entités entre elles, d'extraction de formes à partir de formes déjà créées, de génération algorithmique de formes (formes parallèles, formes développables).
- 2) Les fonctions permettant la modification rapide des objets créés (déformation en continu par poursuite au photostyle)
- 3) Les transformations géométriques : translation, rotation, symétries, homothétie, transformation quelconque, produit de transformations.
- 4) Le traitement ensembliste des entités : par exemple transformation d'un ensemble d'objets...
- 5) Les fonctions de gestion de l'image sur l'écran, à la disposition de l'utilisateur pour assurer l'interactivité graphique dans le processus de création, modification, exploitation des objets : sauvegarde automatique, régénération, remise à blanc, effacement d'une entité de l'écran avec possibilité de la régénérer ultérieurement, destruction définitive d'une entité, possibilité de désignation de n'importe quelle entité sur l'écran : point, courbe, surface.
- 6) Des calculs sur les objets créés: aire, centre de gravité inerties , longueur d'une courbe, rayon et centre de courbure en un point d'une courbe, angle de deux courbes, divisions égales sur une courbe...
- 7) Les fonctions de contrôle et d'exploitation des formes créées : intersections courbe-courbe, courbe-plan, courbe-surface, plan-surface, surface-surface.
- 8) Les utilitaires :
  - liés à la visualisation graphique ; définition d'axes, modification d'échelles, recadrage, perspectives, projections, tracés d'entités.
  - divers : affichage de résultats numériques, fin de session de travail, utilisation des bandes magnétiques...
- 9) La sortie des tracés :
 

Formatage pour la machine à tracer, possibilité de rajouter des textes et des références, choix des vues et des échelles.
- 10) Préparation des bandes d'usinage :
 

Simulation des trajectoires d'outils à l'écran, génération automatique de l'usinage.

#### 7 - EXEMPLE DE CONCEPTION

Conception du raccordement d'une aile et d'un fuselage :

- 1) Définition d'une partie de fuselage (fig. 1)
- 2) Définition d'une partie d'aile (fig. 2)
- 3) Détermination de la courbe limite sur le fuselage et récupération d'une partie du fuselage pour procéder au raccordement (fig. 3)
- 4) Fuselage et aile prêts à être raccordés (fig. 4)
- 5) Génération automatique du raccordement (fig. 5)

#### 8 - BILAN DE L'UTILISATION A MARIGNANE

Les plans de formes de tous les appareils nouveaux sont conçus et tracés en utilisant le système de Conception de Formes. De plus, les moules de pales, d'entrées d'air... réalisés en matériaux composites, sont créés et usinés par le système.

Des comparaisons ont été faites avec les méthodes traditionnelles. Des bilans établis pour la conception et le traçage de plans de formes par des utilisateurs du système dans l'entreprise permettent d'afficher les gains suivants :

- 1) Gains en coût :
 

Supérieurs à 25 %, ils atteignent fréquemment 50 à 70 % (compte tenu des frais informatiques).
- 2) Gains en délais :
 

Supérieurs à 50 %, ils peuvent atteindre 90 %. Ces gains, variables selon le type des applications traitées sont particulièrement importants dans le cas de problèmes algorithmiques.
- 3) Gains en qualité :
 

Il est très important de noter que, puisque par l'emploi de telles méthodes, les modifications sont très rapides, dans une même période, diverses solutions pourront être étudiées. Par là même, il y a gain de qualité.

## 9 - CONCLUSION

Dans l'avenir, ces gains pourront être augmentés en assurant une diffusion encore plus large du système dans l'entreprise.

Pour cela, le développement se poursuit dans trois voies principales :

- une amélioration constante de l'interface homme-machine.
- l'extension du système pour le rendre capable de traiter les problèmes de conception de pièces simples, de manière rentable.
- La rationalisation de la gestion des objets créés, en introduisant un système de gestion de bases de données d'un type nouveau.

Celui-ci, actuellement en cours d'étude, pourra être le noyau fondamental du système intégré de Conception et de Fabrication Assistées par Ordinateur, vers lequel tendent les travaux en cours à l'Aérospatiale Marignane.

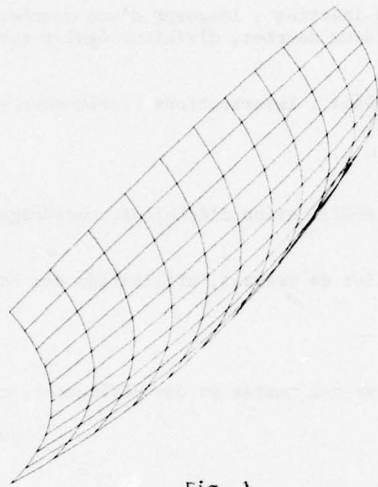


Fig. 1

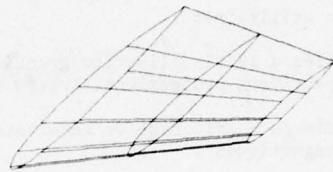


Fig. 2

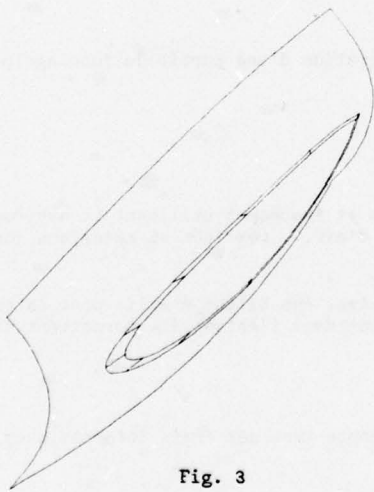


Fig. 3

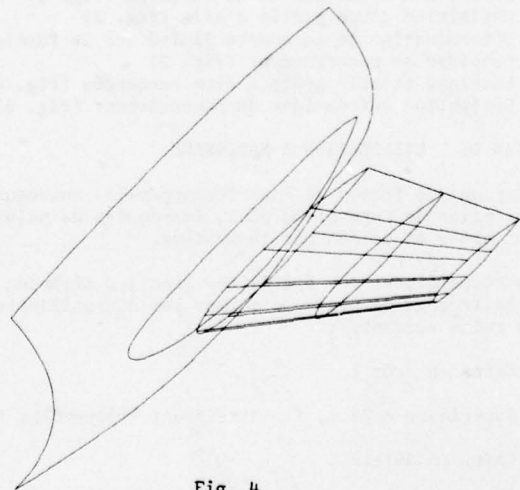


Fig. 4

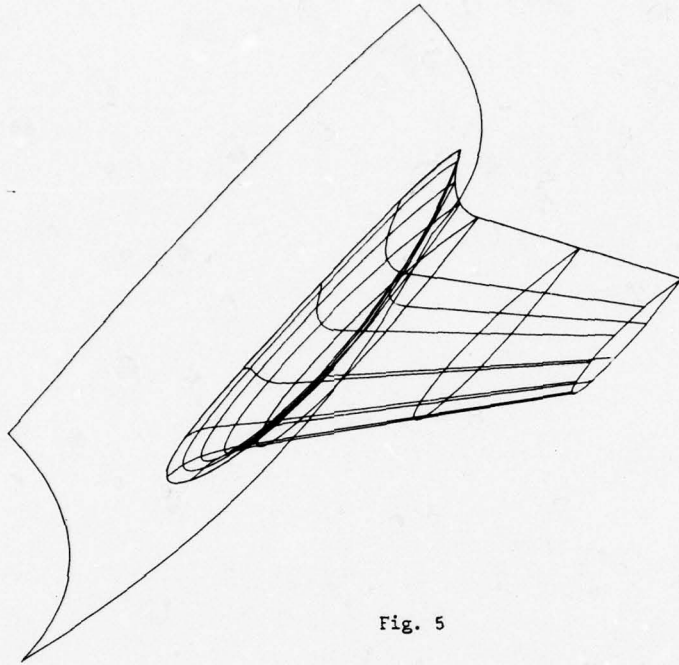


Fig. 5

DRAPO : UN SYSTEME DE CONCEPTION  
ET DE FABRICATION ASSISTEES PAR ORDINATEUR

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FRANCE

RESUME

La recherche d'une optimisation maximale dans la réalisation d'avions de plus en plus complexes a conduit la Société des AMD-BA à mettre en place progressivement un système totalement intégré de conception et de fabrication par ordinateur dont le nom DRAPO signifie : DEFINITION et REALISATION d'AVIONS PAR ORDINATEUR.

DRAPO peut se définir, d'une part par le matériel adopté dont le choix détermine le mode d'utilisation, et d'autre part par ses fonctions principales.

La présente note - après une brève introduction exposant les motivations et les buts recherchés par la Société des AMD-BA dans la mise en place de ce système - a pour objet de décrire les principaux aspects de DRAPO et d'illustrer son utilisation par quelques exemples.

INTRODUCTION

L'évolution simultanée de l'aérodynamique théorique, dont les calculs sont la première étape de la conception d'un avion, et de l'usinage par commande numérique, dernière étape de la réalisation des pièces de structure principales, est à l'origine du système DRAPO.

En effet, au cours des quinze dernières années, l'aérodynamique théorique, dont les méthodes de calcul ont considérablement progressé grâce à l'ordinateur, est à l'origine d'une recherche de la définition précise par l'informatique des surfaces complexes qui constituent la peau de l'avion. Dans le même temps, l'utilisation croissante des machines-outils à commande numérique a eu pour conséquence la recherche d'une définition numérique de la géométrie des pièces de structure.

Dès lors, l'informatisation complète du processus de conception et de fabrication d'un avion est devenue inéluctable et s'est réalisée progressivement. Les ressources de l'ordinateur justifient cette évolution :

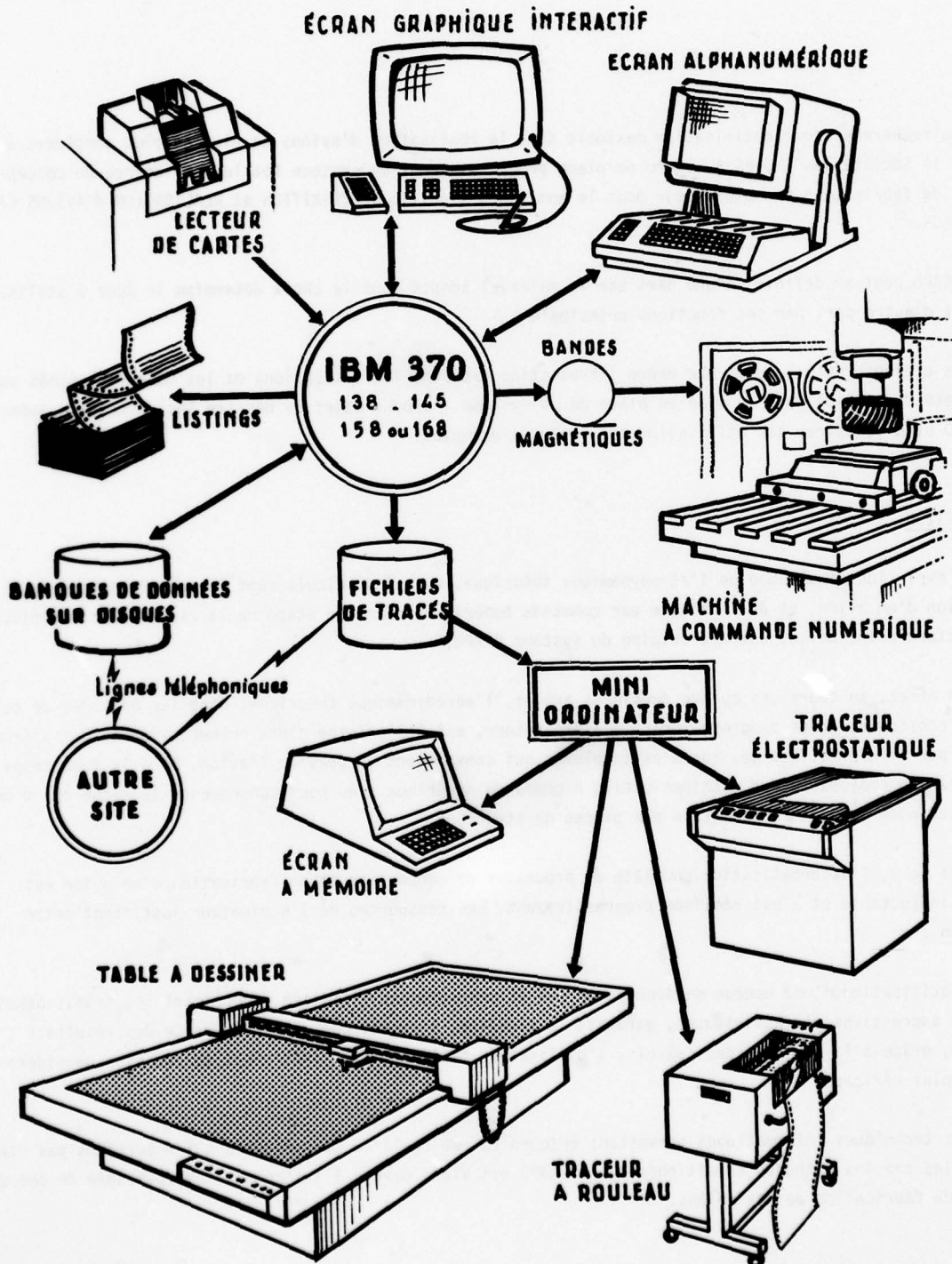
L'utilisation d'une banque de données unique et pratiquement illimitée, supprimant les traditionnelles copies successives et fastidieuses, garantit la fidélité, l'exactitude et la cohérence des résultats ; en outre, grâce à la rapidité des calculs, l'utilisateur bénéficie d'un instrument de décision considérablement plus efficace.

Ces techniques informatiques permettent aujourd'hui de réaliser des produits qui n'auraient pas été concevables par les méthodes traditionnelles : DRAPO est alors devenu l'instrument indispensable de conception et de fabrication de nos avions.

Toutefois, cette évolution - ou révolution - des méthodes de réalisation des avions ne pouvait vraiment aboutir sans la satisfaction d'une autre ambition : l'établissement d'un dialogue entre l'homme et l'ordinateur permettant d'allier la rapidité et la puissance de calcul et de traitement de l'information propre à la machine avec le pouvoir de décision, la créativité et l'expérience de l'homme. C'est l'ambition avouée des responsables de DRAPO.

### 1 - LE MATERIEL

Chaque usine dispose d'un centre informatique dont l'organisation est schématisée ci-dessous :



### 1.1 - Les unités de calcul

Les unités de calcul du système DRAPO sont des ordinateurs IBM de la série 370. Les besoins propres à chaque usine de l'entreprise ont déterminé le choix du modèle : 138, 145, 158 ou 168.

### 1.2 - Les moyens de dialogue

Les interfaces entre l'opérateur et l'unité centrale sont multiples : terminaux alphanumériques IBM 3270 ou MEMOREX 1377 ; terminaux graphiques interactifs IBM 2250, ADAGE GT/2250 ou, plus récemment, IBM 3250.

L'opérateur dispose au moins d'un clavier alphanumérique et d'un écran, instruments indispensables de son dialogue avec l'ordinateur. Les terminaux graphiques interactifs visualisent des points, vecteurs, courbes ou messages et offrent deux dispositifs supplémentaires de dialogue : un crayon photosensible, ou "photostyle", et un clavier "de fonctions" comportant 32 touches.

Chaque touche du clavier de fonction est associée à une tâche déterminée : en appuyant sur l'une d'elles, l'opérateur déclenche un calcul qui fonctionne sur un mode interactif dont les entrées proviennent du clavier alphanumérique ou du crayon photosensible. Ce dernier est un instrument très précieux de sélection rapide des éléments visualisés.

L'écran graphique est constamment rafraîchi : cette caractéristique fondamentale, qui le distingue des écrans "à mémoire", autorise une remise à jour instantanée et permanente de l'image et facilite considérablement le dialogue.

### 1.3 - Les traceurs

Sur chaque site, une ou plusieurs machines à dessiner sont pilotées par un mini-ordinateur relié à l'ordinateur local. Cette configuration permet d'effectuer un tracé sur l'une quelconque des machines, grâce à un logiciel universel.

Les besoins locaux justifient le choix de ces terminaux en fonction de leurs caractéristiques : ce sont, soit les traceurs à tambour, économiques et relativement rapides, soit les tables à dessiner, souvent de grande dimension, véritables machines-outils capables de tracer avec une grande précision à la plume sur du mylar ou à la pointe diamant sur la "carte à graver".

Plus récemment, les traceurs électrostatiques se sont imposés dans les bureaux d'étude : leur principe de fonctionnement les rend extrêmement rapides; en outre, leur précision et leur résolution sont comparables aux traceurs à tambour ; ils restituent, par exemple, un dessin complet de cadre principal d'avion en quelques minutes.

### 1.4 - Le télétraitement

Les ordinateurs de chacune des usines sont reliés entre eux par des lignes téléphoniques permettant l'établissement de liaisons entre les fichiers disques, à tous les niveaux et à chaque étape du processus d'exploitation de DRAPO.

C'est ainsi que les formes - surfaces complexes, géométrie des éléments de structure - qui ne sont définies que dans les usines disposant d'un bureau d'études de conception, sont transmises aux usines de fabrication.

Ces liaisons améliorent, par ailleurs, la répartition des charges de travail et optimisent l'utilisation du matériel dont certains éléments très spécialisés ne sont pas disponibles sur tous les sites. C'est le cas, en particulier, des machines à dessiner de très grande dimension (7,2 m x 1,8 m).

## 2 - LE LOGICIEL

Certains principes de base définissent les règles d'utilisation des programmes DRAPO et sont à l'origine de la création d'une bibliothèque de sous-programmes extrêmement généraux.

Ce sont, par exemple, les routines d'archivage et de recherche des éléments identifiés par un titre dans la banque de données : elles autorisent, en lecture et en écriture, un accès simultané de plusieurs utilisateurs de DRAPO. D'une manière générale, chaque entité géométrique - courbe, surface, volume, dessin, etc... - est identifiée par un titre et archivée dans la banque de données.

## 3 - LES FONCTIONS PRINCIPALES DE DRAPO

Dans son état actuel, DRAPO intègre trois fonctions principales. Chacune d'entre elles est une aide de l'ordinateur aux différentes étapes chronologiques de la réalisation d'un avion : la définition des formes, la conception par le dessin et la fabrication.

### 3.1 - La définition des formes

Cette fonction, initialement inspirée par les besoins de l'aérodynamique théorique, s'est progressivement substituée au traçage manuel. Elle est aujourd'hui l'outil de définition des formes de l'avion : surfaces externes et références internes de cadres, voiles, nervures, etc...

Les formes sont archivées dans une base de données tridimensionnelles unique pour l'entreprise, sous la responsabilité d'une équipe restreinte, gage de sécurité dans la coordination de nombreuses contraintes de définition émanant des bureaux d'études, des services d'Aérodynamique théorique ou expérimentale et de la fabrication.

La génération des formes d'un avion est un jeu de construction dont les pièces de base sont les courbes, les surfaces et, au plus haut niveau, les volumes.

#### a) Les courbes

Une courbe est la fonction d'interpolation d'un nombre limité de points. En certains points, sont associées une direction tangentielle orientée et, éventuellement, une courbure. Cette dernière contrainte permet de contrôler l'écoulement aérodynamique.

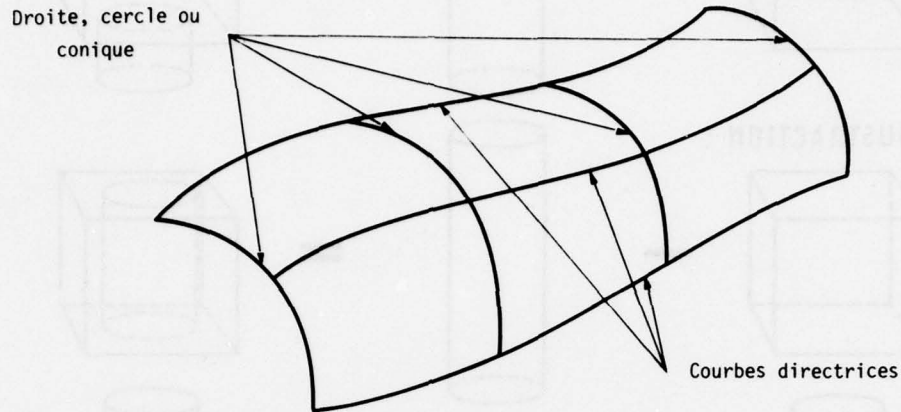
DRAPO calcule, par la méthode des éléments finis appliquée à des polynômes du cinquième degré, la fonction d'interpolation la plus "lisse" garantissant la continuité des courbures et même de leurs dérivées.

Une console graphique interactive visualise la courbe calculée et ses évolutions de courbure : l'expérience montre alors qu'un écran de faible dimension, grâce à cette représentation quantitative, remplace efficacement une grande table de traçage traditionnelle. L'opérateur modifie à son gré les contraintes - points, tangentes, courbures - et obtient instantanément une nouvelle répartition des courbures. A l'inverse, s'il attribue à chaque point une tolérance, un calcul de lissage automatique détermine la courbe optimale.



### b) Les surfaces

L'utilisateur dispose d'une panoplie de surfaces spécialement adaptées aux formes d'un avion : elles sont générées par des segments de droite, des arcs de cercle ou de conique qui s'appuient sur des courbes directrices.



Chaque type de surface offre au concepteur une grande variété de choix, en fonction du résultat recherché. Dans le cas d'une conique, par exemple, il sélectionne les cinq paramètres indépendants de sa définition, par les données d'un nombre suffisant de points et, éventuellement, de tangentes ou de courbures associées.

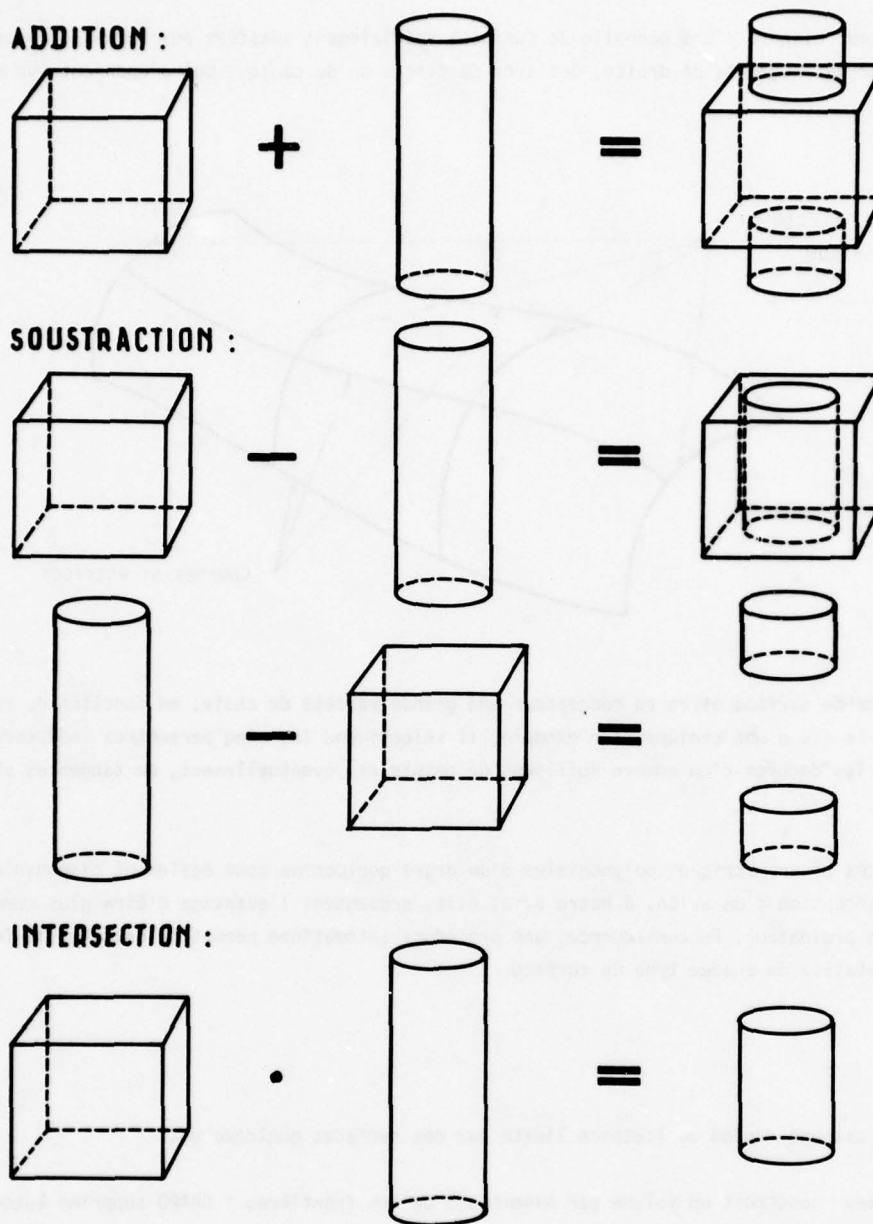
Les surfaces biparamétriques polynomiales d'un degré quelconque sont également disponibles. Moins adaptées à la conception d'un avion, à notre avis, elles présentent l'avantage d'être plus commodes à exploiter par un ordinateur. En conséquence, une procédure automatique permet de calculer la forme polynomiale représentative de chaque type de surface.

### c) Les volumes

Un volume est une région de l'espace limité par des surfaces quelconques.

Le concepteur construit un volume par assemblage de ses frontières : DRAPO supprime automatiquement les nappes de surfaces inutiles et calcule les arêtes du volume. Des opérations d'addition, de soustraction et d'intersection (voir figure jointe) assemblent automatiquement les volumes entre eux et génèrent ainsi des ensembles dont la complexité n'est pas limitée.

Un volume est défini, dans la banque de données des formes, par une structure logique dont certains pointeurs font référence aux surfaces frontières. En conséquence, la modification d'une ou plusieurs frontières ne nécessite pas une nouvelle définition du volume associé : il en résulte un gain de temps et de sécurité important pendant la phase de conception.



### 3.2 - La conception par le dessin

La console graphique interactive est devenue le nouvel outil du dessinateur de bureau d'études. L'écran tient fonction de planche à dessin ; le photostyle joue le rôle d'une gomme et d'un crayon.

La technique de conception n'est pas modifiée. En effet, le dessinateur reste un disciple de Monge, il étudie les figures de l'espace à partir de leurs projections sur des plans perpendiculaires entre eux. Une pièce de structure, "dessinée" avec l'aide de l'ordinateur, archivée dans la banque de données, est définie par des projections, des sections rabattues, éventuellement des perspectives.

Mais l'outil du dessinateur n'est plus comparable. Il profite désormais des ressources de l'ordinateur : rapidité du calcul, précision et fidélité des informations, automatisation du tracé des dessins.

Le concepteur peut créer un grand nombre de figures géométriques : points, droites, cercles, coniques, courbes, textes. Les courbes sont éventuellement obtenues par section des surfaces archivées dans la banque de données. Il peut en outre créer des surfaces réglées particulièrement adaptées à la définition des ailes de cadres ou de nervures. Elles sont généralement calculées automatiquement par une schématisation optimale des formes complexes sur lesquelles s'appuient les ailes de la pièce qu'il "dessine".

Le concepteur peut aisément manipuler les figures géométriques en effectuant des translations, rotations, symétries, changements d'échelle. La cotation est automatique. De nombreuses fonctions d'analyse sont une aide précieuse de l'ordinateur : calcul de périmètre, aire, volume, inertie, etc... Une fonction spécialisée détermine automatiquement le contour à plat des pièces de tôlerie.

### 3.3 - La fabrication

DRAPO, dans sa troisième fonction, est l'outil de préparation de l'usinage par commande numérique des éléments géométriques archivés dans la banque de données.

Le préparateur, devant une console graphique interactive, décrit le trajet de la fraise ou sélectionne les figures géométriques sur lesquelles la fraise doit s'appuyer. Il définit en outre la forme de l'outil, le type d'usinage - 3 axes ou 5 axes - et les données technologiques nécessaires.

Un contrôle permanent de l'usinage, par visualisation de la fraise à l'écran, permet au préparateur d'éviter toute erreur et de corriger éventuellement la géométrie de la pièce, afin de mieux l'adapter aux techniques de fabrication.

Certaines fonctions spécialisées automatisent des séquences d'usinage complètes : l'une d'entre elles permet de réduire considérablement les temps de préparation d'outillages plan (dont le nombre s'élève à plusieurs centaines par avion) qui s'appuient sur les formes externes. Une autre fonction spécialisée définit automatiquement l'usinage d'une surface complexe.

## 4 - LA MISE EN OEUVRE DE DRAPO

Deux cents ingénieurs et techniciens environ, répartis dans six usines de la Société, utilisent DRAPO quotidiennement.

Ils effectuent couramment des sections par des plans quelconques et tracent des projections, des perspectives cylindriques ou coniques des formes archivées dans la banque de données. Deux exemples illustrent cette application sur un avion militaire (figure 1) et un avion civil (figure 2).

Les contours d'un grand nombre de pièces de structures internes (cadres, nervures, etc...) sont des sections de surfaces parallèles aux formes de base : l'utilisateur définit alors simplement une distance aux surfaces de référence, généralement égale à l'épaisseur de la peau de l'avion.

Le calcul des normales est un préalable aux traitements d'aérodynamique théorique et d'usinage par commande numérique.

La figure 3 est un cadre principal d'avion militaire, "dessiné" sur une console graphique interactive et archivé dans la banque de données. Les ailes du cadre sont définies automatiquement par des surfaces réglées schématisant de manière optimale les surfaces parallèles aux formes de référence, à une distance égale à l'épaisseur de la tôle de revêtement. La préparation de leur usinage sur machine à commande numérique "5 axes" est une fonction spécialisée du programme interactif d'aide à la fabrication.

Des applications classiques de la géométrie descriptive sont illustrées par les figures 4 et 5. Une épure de la cinématique d'un train d'atterrissage (figure 4) et une perspective d'un élément de structure "dessinée" à l'aide de deux projections (figure 5) ont été réalisées très rapidement sur une console graphique interactive.

La figure 6 est un schéma de circuit électronique réalisé à l'écran. Chaque composant est représenté par un symbole archivé dans une bibliothèque spécialisée gérée par l'utilisateur.

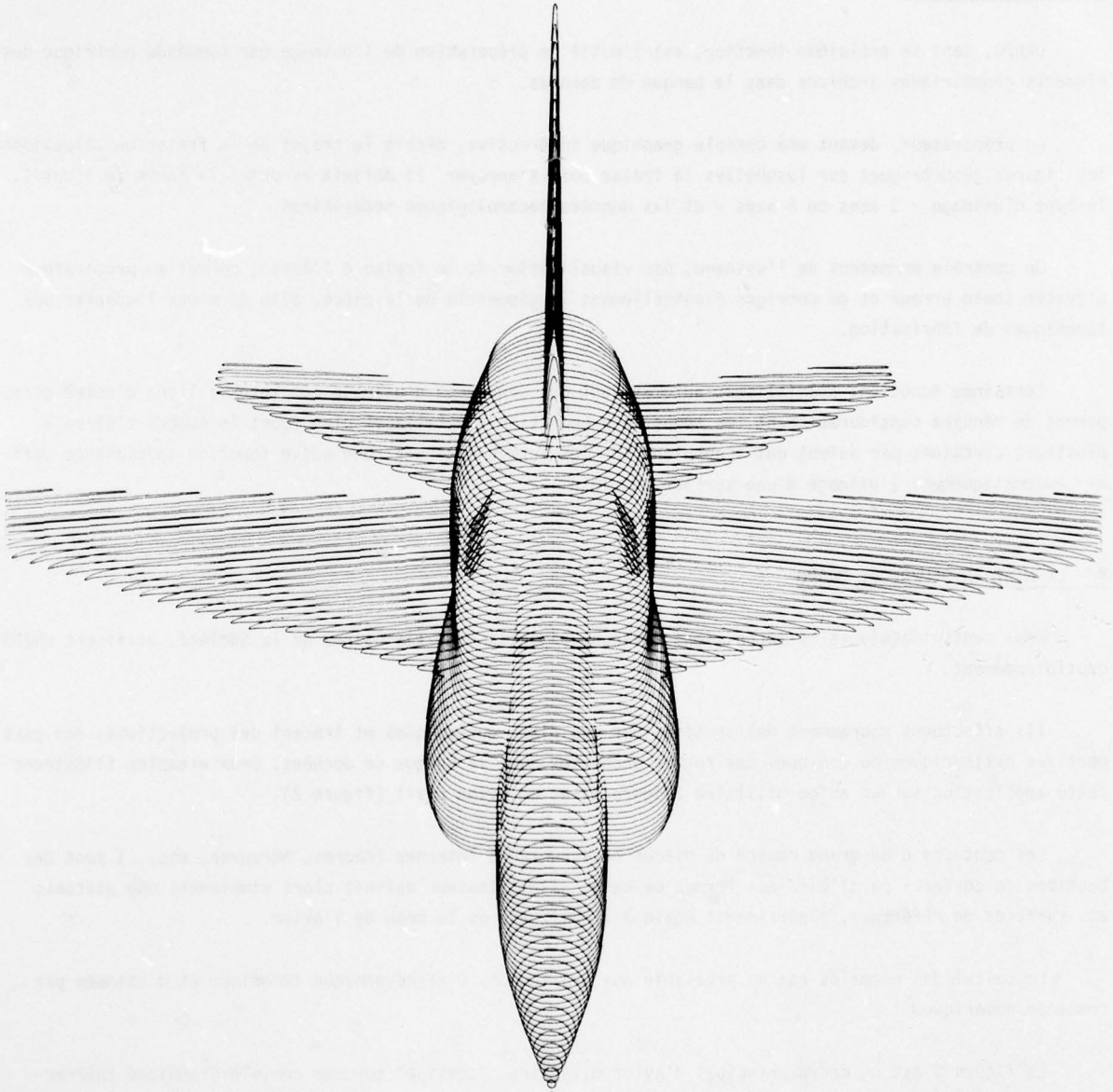


Figure 1

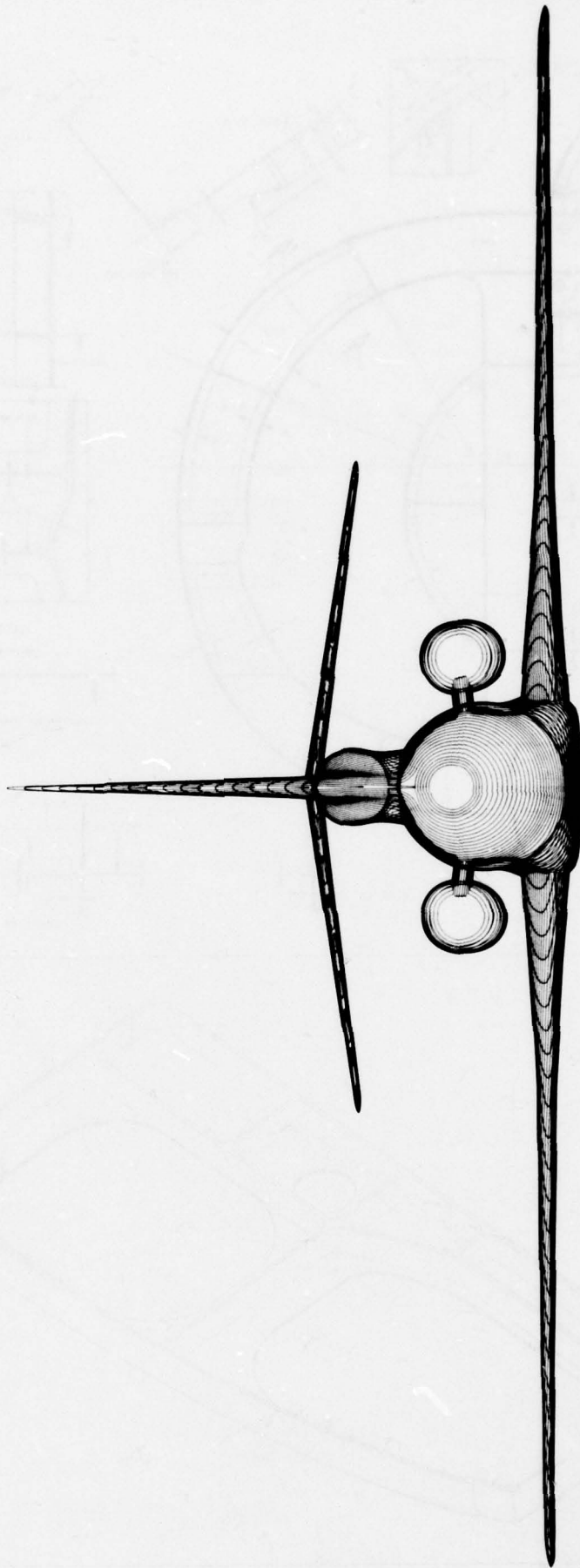


Figure 2



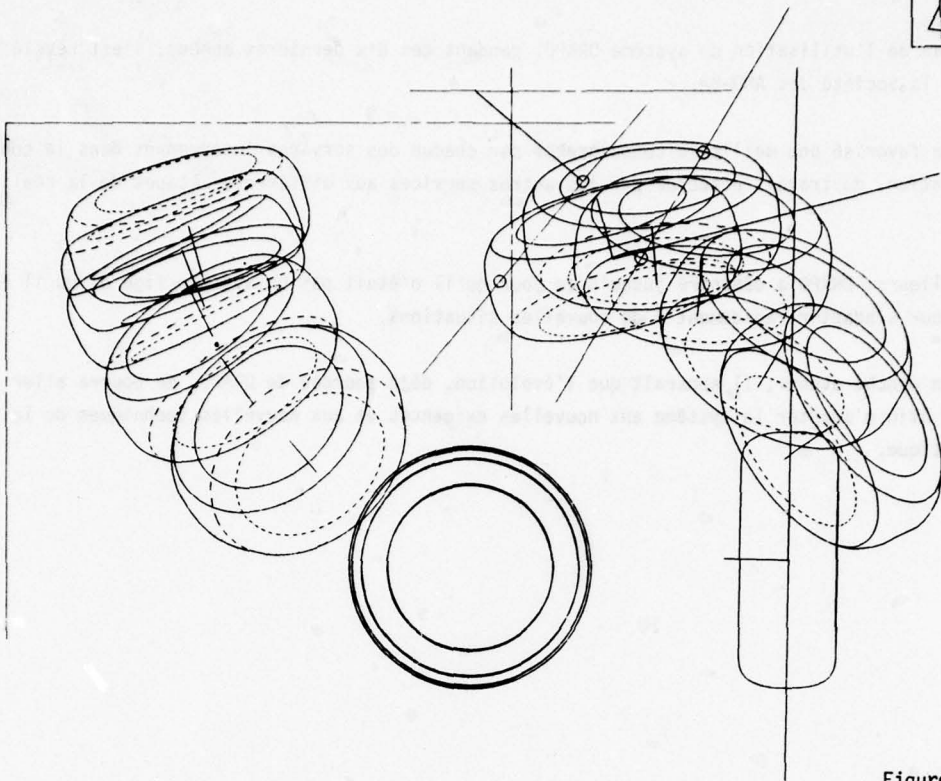


Figure 5

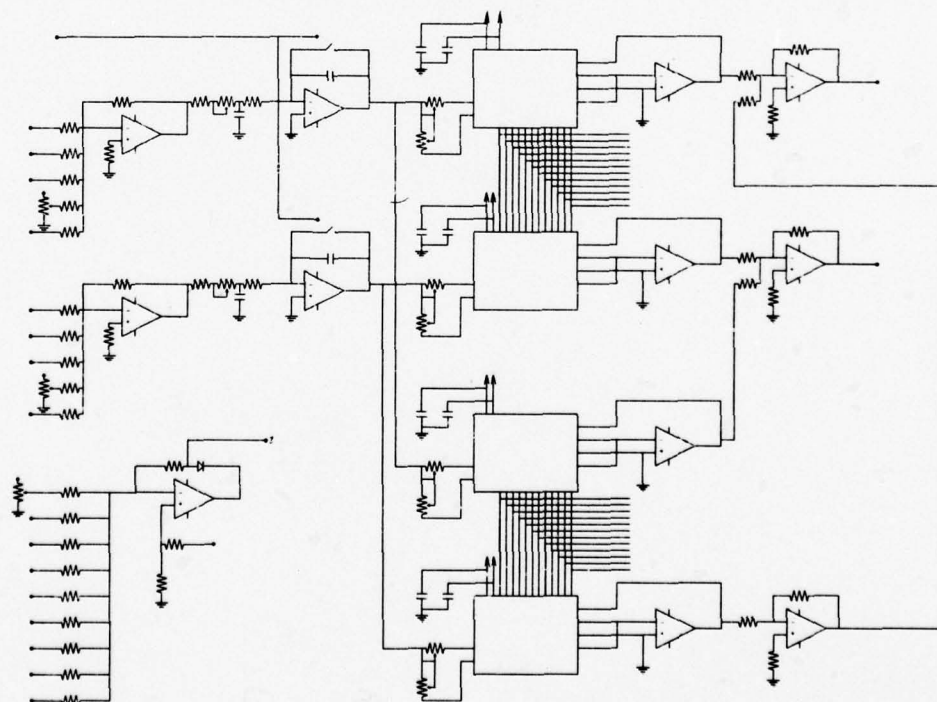
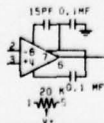


Figure 6

ERBLAGE 559



CONCLUSION

Le bilan de l'utilisation du système DRAPO, pendant ces dix dernières années, s'est révélé très positif pour la Société des AMD-BA.

DRAPO a favorisé une meilleure connaissance par chacun des services intervenant dans la conception et la fabrication, du travail effectué par les autres services aux différentes étapes de la réalisation de l'avion.

Par ailleurs, DRAPO a démontré jusqu'à ce jour qu'il n'était pas un système figé et qu'il était bien conçu pour s'adapter rapidement à de nouvelles situations.

Dans un proche avenir, il apparaît que l'évolution, déjà amorcée de DRAPO, ne pourra aller qu'en s'accroissant afin d'adapter le système aux nouvelles exigences et aux nouvelles techniques de la construction aéronautique.



Some requirements for a communication system guiding the relations between the design engineer and a general data base

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### Summary

During the entire design process there should be a very close connection between the design engineer and a general data base. This connection is accomplished by a hardware and a software system which is called the communication system. The layout of such a system depends on the point of view. In this paper only two different configurations are presented.

The first one is seen from the user who expects the system to be simple in usage and guiding him through the design process.

The people involved with the development of such communication systems want to remove most of the manual components and obtain almost complete support of the designer in all phases of the design process. These intentions let the system become very complex and hardly can match the users requirements on simplicity.

Finally a model for possible cooperation during the development of a general communication system is described, in order to achieve standardized components in similar design offices.

### Introduction

Intensive application of electronic data processing in different commercial branches has led to considerable success. This can be observed almost since the first introduction of this new means supporting man for example in handling great amount of data with very high speed. Similar success expressed in sizable reductions of cost and time is now expected when extending computer assistance to a classical engineering field, the design process. This application is well known as 'Computer Aided Design' (CAD).

Some typical developments in the past two decades have shown that there are also during the process of design engineering different tasks which can be supported effectively by electronic data processing. So for a long period of time almost all significant developments in computer aided design were focused on iterative analysis methods as f. e. the finite-element stress analysis or the finite-difference method where in a similar way as in commercial data processing a great amount of input and output data has to be prepared, calculated and evaluated, respectively. Graphical input and output devices came into use in order to help the designer when preparing his input data and afterwards allow a very quick interpretation and checking of the results.

In parallel there have been increasing efforts to develop computer-aided-design systems which should produce complete technical drawings with direct support by graphical devices using intensively the interactive technique. Some of these systems have reached a very high technological level and are made available commercially to potential users. They are obviously suitable now to be introduced on a broad basis into the design offices.

There are basically three major components extensive CAD-systems might be divided into. In general these components are the

- general data base, the
- CAD-software, and the
- communication system

One part of the general data base is used to store away all data arising during the design process ( drawings usually contain geometrical data, technological data and administrative data ). These data are managed by the data base management system which provides also the user with access to all data within the data base and enables him to exchange data with other users.

All software packages placed at users disposal for example for drawing creation, stress calculation etc. are collected in the CAD-software.

The communication system comprises all general software modules necessary to input and output information to be either further converted by the design engineer or to be documented as drawing or in a more general way. In addition the communication system contains all program modules which determine the working technique in the different stages of the design process. Furthermore all hardware components which enable the user to input information or to get data out of the system are part of the communication system. Because of its iterative character and dynamic nature the design process requires a high level of interaction. So the user in the design office on the one hand has special requirements to the hardware components being used to perform the dialogue; on the other hand the question how the dialogue itself is carried out is of great interest.

### The 'users' model

Most of the companies are still organized in a way that when developing a new product especially during the design process there are a lot of different researchers and departments using their CAD-modules and all will have individual requirements. From the designers point of view the hardware components used to cope with the computer and of course the conditions of the dialogue itself are the most important points of interest. At present the display console seems to be the only hardware device which is able to match in a satisfactory way the requirements of the user when interacting with the computer. Only the type of console, its location and its availability will be redefined depending on the particular task to be performed.

Especially the design engineer who can still be said to be normally a layman as far as data processing is concerned expects when abandoning his accustomed set of tools that he gets another but nevertheless completely equivalent means at his disposal. When considering the 'natural' procedure of the design process where ruler pencil and paper as working medium are used in connection with a drawing board then obviously the display console with light pen could play an almost equivalent role in the relationship between designer and data base, of course depending on hardware extension by software. Drafting with a lightpen on an electronic screen is in some respect a similar function to drafting with a pencil on a drawing board. So the screen area is required to be as great as possible and in addition the console itself should be of variable inclination in order to be adapted to the physical conditions of the individual design engineer. Furthermore the designer presupposes to have his own screen at his disposal. From the economical point of view this requirement can't be maintained because a certain number of designers will have to share one display console in order to achieve an economical charge.

Following the procedure of designing a new product there is a first stage with a great need for data being relevant to the design project. When performing this phase also with the CAD-system the presentation of these information in adequate graphical or alpha-numerical form is required. Therefore one or more additional screens are needed. In doing so the object on the main screen has not to be deleted and afterwards redrawn when the display of information is terminated. The evaluation of these information in general needs no high degree of interactivity so one way graphics will be sufficient for these purposes. The screens are used only for message transfer and so are called 'message' screens.

But on the other hand a very high degree of reliability of all hardware components used for interaction is essential.

Beside the hardware configuration the conditions of the dialogue itself are of great interest for the designer. Satisfactory interaction will depend on two major factors which are the

- general layout of the screen, and the
- library of subroutines and functions  
being represented in the menu

The screen has to be divided into the framed working area and the separate information area. The light buttons to be picked by the user have to be located such that they can be reached easily. According to their meaning light buttons with similar functions should be grouped together in the menu. Significant light buttons as f. e. for job termination or discontinuation are to appear on the screen always at the same location, also when changing control from one program module to the other, in order to be issued at any time desired. The meaning of a particular light button has to be recognised only by its mnemotechnique structure. So the terms chosen should be borrowed from the terminology used in the design office in order to be kept easily in the users memory and so learned quickly.

As during the entire design process an intensive dialogue has to be maintained the systems response time must lie within an acceptable order of magnitude; derived from experience this time should be below 1/2 second.

Although the designer will still feel as innovator and decision maker skilled in doing the heuristic parts of the process he wants the computer to play an active role when performing the dialogue, in other words he expects the system to guide him through the design process in using marked steps and offering adequate functions at the defined design stages. There must also be a quick and efficient diagnostic system in order to send messages and correct errors caused by the user. A set of error functions is needed either to delete the wrong actions or to transform them into valid ones.

The process of designing is normally begun with the planning phase and is terminated when the complete drawing is transferred to the production line. Rough drafts derived from conception are refined to detail drawings which then need to be checked, released and distributed. All these activities lie between the above mentioned two points. So beside the elementary functions for graphical input, object manipulation and modification a lot of functions supporting these working areas are required. Access to engineering information like standards, national and international, access to drawing files are of interest in the pre-geometric-input-phase. Highly schematic parts of draftings should be reproduced only by supervision of the design engineer or draftsman. The control and final check of formal elements of the produced drawing should be performed automatically by the system depending on users demand. The stored drawing can also supply all data necessary to generate the parts list half automatically. The list will then be completed by the designer himself. Drawing release, using checkpoints, sealing and distri-

bution should also be performed by the system in order to free the designer by this non creative activities.

As conclusion of this chapter a short summary of the main users requirements should be given: When abandoning his accustomed set of tools the designer expects a working station of very high reliability supported by software packages which enable an intensive interaction between man and computer in such a way that the designer will retain the heuristic and creative work and will be freed from routine activities now performed by the computer.

#### The 'developers' model

Designing and developing a new CAD-system often answers the question how to produce typical results of any design process in the most efficient way. So the practice of the design engineer who is skilled in visual thinking is normally not the dominant design parameter within the set of design criterias. The developers often presuppose that a new kind of design engineer will operate the complete system. The system itself comprises a lot of program modules which guarantee a continuous support in the entire design process.

When restricting to airframe manufacturing beside drafting the main working areas are loft calculation, static and dynamic stress calculation, determination of loads and weights as well as the general problems of administration in the design office.

At present in many companies this work is still done by specially educated personnel. As can be recognised in the past this growing specialisation often had led to barriers even between adjacent working areas and so had sometimes complicated the flow of information. Now, when using CAD-systems which support almost all working areas in an equal way these barriers might well be wiped away in the future because the information exchange will always take place via the general data base. So the efficient use of the complete CAD-system could in fact require a new kind of user. This general design engineer will then have to perform all tasks which are now still distributed to different persons.

But when reasoning about this problem the reality should always be kept in mind and therefore two different ways should perhaps be followed:

- Today's CAD-systems which are ready for being introduced into the design office have to be operated by the existing personnel and so even significant modifications have to be taken into account in order to tailor these systems to users requirements. That means in general that each working area will use its own CAD-module whose results will be transferred often manually to the next department. The aforementioned barriers will still be maintained which is of course a disadvantage.
- The CAD-systems which guarantee the complete support of the design engineer will probably not be implemented in the next 5 years but then will be used on a broad basis. All tasks of the classical design process will then be performable by only one user communicating very intensively with the computer.

When extrapolating very cautiously the hardware development to the same timespan of about 5 years one can expect the communication to be done with similar display consoles as we know today. Derived from experience we also know that the development of great software packages is a very time consuming process. This must not be only a disadvantage because there is the chance to start users education in parallel with the program development. The education should be primarily directed towards the deepening of the engineering knowledge, especially design engineering as drafting, loft calculation etc.. Of course there should be a basic knowledge of data processing as f.e. computer graphics.

This education will then enable the design engineer to perform all heuristic parts of the design process in connection with the CAD-system which has to support all functions necessary to free him from manual activities. Of great importance will be the permanent dialogue between system designer and design engineer in order to find out the real applicable system which might be possibly a hardware mixture of drawing boards and display consoles. The first ones used to draft in the conceptual phase and the other ones for detail drawing and information access.

#### The 'cooperation' model

Probably the development and realisation of such an integrated CAD-system can no longer be performed by only one company. If only the costs which are about 100-200 man years in amount are taken into consideration one has to look for suitable models for national and even international cooperation. Such cooperation would be even desirable only in order to avoid parallel development of system components which do not depend from a particular company environment. Of course an extensive system can only be developed when following well defined steps. So the system development should be started with a survey of all necessary research work collected in a system catalogue. This catalogue should contain beside others the following design criteria, mentioning of course the already computer supported components.

- hardware
- software
- interface
- human engineering
- social aspects
- economic aspects
- acceptance by user
- user education

The items must be detailed and then be distributed to the companies following the cooperation model. The contributions of the different companies to the system development will then be of a very high quality because the researchers can concentrate on the solution of one or only two problems out of the catalogue. Of course there should be a permanent discussion between the people involved with the development. So for each of the above mentioned areas basic models could be offered. These models can then be easily tailored to the particular need of the companies. Each company will profit of the design work contributed by the other companies. So at least the keypoints of development would be almost the same ones in all companies and so lead to standardized system components in the design offices.

## CAD FOR ELECTRIC SYSTEMS DESIGN

by

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### SUMMARY

Modern high-performance aircraft design requires the generation of a large amount of paperwork, which has to be prepared for aircraft production. Especially in electric design a lot of data is defined by standards, supplier lists and specifications.

To convert these data into drawings and information for production a lot of manpower would be necessary to reach scheduled target time for a running project.

CAD has opened a new way to meet design needs with respect to speed, reliability and costs savings.

The system now in operation at MBB is shown.

Development is continuing in cooperation with production and service engineers to accomplish CAD for electrics.

### 1. INTRODUCTION

Computer aided generation of wiring diagrams is considered to be one part in an integrated circle of data processing activities performed or planned in the area of electrics in design and production (Fig. 1).

This point finally results from the fact, that for design people, generation and modification of the graphic information in wiring diagrams cannot be separated from storage and maintenance of the wiring logic i.e. identification of wires and connectors, their interrelations, and all the other information which is contained in the wiring diagram.

The logic of the wiring diagram stored in a data base is the prerequisite for outputs used in the design office.

### 2. GRAPHIC INTERACTIVE DESIGN OF WIRING DIAGRAMS (Fig. 2)

In 1975 a study "Graphic Interactive Design of Wiring Diagrams" was carried out using an IBM 2250 display unit and a Kingmatic NC-Drafting machine.

A small set of about 20 frequently used graphic symbols on diagrams were stored as macros and positioned on the screen by use of light-pen and function keyboard.

Using this system the designer was able to create or modify parts of a wiring diagram to link together several parts to one complete drawing and to produce automatically from the stored drawing a control-tape for off-line drafting machine.

As a result of this study some requirements became evident:

- o The possibility to start from a sketch and to input this sketch by a tablet.
  - o A more economic hardware equipment but with a high capacity of storing graphical elements.
  - o A comprehensive library of frequently used symbols.
  - o To be able to create or modify simultaneously a data base of the diagram logic as the most important requirement.
- Further development in this area was stopped due to higher priority of other areas for running projects in the design office.

### 3. CAD IN ELECTRICS

Producing a modern aircraft can require more electrical information and drawings than wires, plugs and pins.

Traditionally, engineers sketch and calculate, then draftsmen draft and typists write. Then engineers discover needed changes or improvements, and draftsmen draft and typists write some more. A lot more.

In 1974 MBB started with CAD in the Electrics as a direct link to deliver information and drawings for production purposes.

CAD has opened a new way to meet design needs with speed and reliability for complex integrated circuits of highperformance aircraft.

### 3.1 System in operation

For manufacturing aircraft the design office in the electrical area mainly has to deliver data and information for

- o Producing harnesses
- o Checking and testing harnesses after installation
- o Printing technical handbooks for maintenance purposes.

This "SYSTEM IN OPERATION" is shown on Fig. 3. It is mainly based on the lot of information and data stored in the data base of electric.

#### 3.1.1 Stored information

The present system now in operation is based on the stored information. For harness design, drawing preparation, harness manufacturing, testing and handling purposes the following information and data are necessary:

- o Diagrams (conventionally produced)
- o Manufacturing Data
- o Vendor Data and Standards.

The Circuit and Wiring Diagrams (Fig. 4) detail the circuit of a particular subsystem. These drawings outline the installation requirements and indicate the interconnection of equipment. The location of the equipment in the major aircraft sections already is shown, as well as switch operating positions, contacts and terminals, wire types and sizes.

Manufacturing Data determines wire length markings, EMC-class, screening, Type of connector.

Vendor Data is shown on the equipment list, which contains the details of all equipment having electrical connections, shown on the circuit and wiring diagram. In addition other information is called up and taken from the equipment parts list. Standards are the base for project design with all the information for design and manufacturing, i.e. insert arrangements, insulations, sealings, method of assembly.

All this data to be stored in the data store is divided in three data groups (Fig.5):

- o Project Independent Data
- o Project Dependent Data
- o Documentation Data

##### 3.1.1.1 Project independent data

The package of information and data consist of Equipment Data delivered by the supplier with Type or Ident.No., title, weight, accessories, specifications and standards, connection lists, connector types, connection means and Wire Data with wire codes, contacts and pin information, weight, size, voltage, resistance, connection means and tooling instructions.

##### 3.1.1.2 Project dependent data

This information is already based on aircraft design consisting of detailed data like equipment and wire idents, wire length, screening, required manufacturing procedures, arrangement of terminals within connectors and module blocks, and installation details. Data of wires-connectors interrelations is taken from conventionally produced wiring diagrams.

##### 3.1.1.3 Document Data

The Document Data contains information about effectivity of drawings, part numbers, drawing issue, type of document, shown object, responsibility.

#### 3.1.2 Output derived

The most important output for design and production preparation are the legal documents for

- o Harness Manufacturing
- o Harness Testing
- o Handbooks

All information necessary is listed in files, is always up-dated and can be printed out.

#### 3.1.2.1 Harness manufacturing

The following files are available:

Harness Wire Lists (Fig. 6) with information about effectivity, from/to equipment, wire data as wire idents, codes and length.

Wire Cutting Lists (Fig. 7) with wire code, length, wire idents, colour, connection means, equipment ident.

Terminal Marking Lists (Fig. 8) with information for sleeves, code, colour, length, identification.

Connection Lists (Fig. 9) with tool information i.e. for crimping: crimping tool, locator, insert, removal, seal plug, special pin.

Connector View (Fig. 10) with information for pin arrangement.

#### 3.1.2.2 Harness testing

The following files are available as a programming aid for cable testing with FACT (Flexible-Automatic-Circuit-Tester) at the fully equipped aircraft:

Wire Lists with information per system and aircraft.

Wire Logic with information for sequence, equipment wiring and marking of test points.

#### 3.1.2.3 Handbooks

The following files are available:

Effectivity Lists of diagrams.

Equipment Lists with all reference information and data of supplier, Ident.No., Vendor Part.No.

Connection Lists with all information of pin arrangement, Ident.No., Standards.

### 3.2 Future development

Now in preparation are parts of the system to derive the bill of materials of harnesses from information which is already stored. Planned or under consideration is the control of various automated production and inspection processes-like terminal marking, wire cutting and preparing, NC harness manufacturing, and circuit testing - by means of the information of a common data base as well as the assistance in preparing service manuals as far as wiring is concerned. Finally - as already indicated - it is planned to merge graphic interactive design and modification of wiring diagram with the input- and alteration procedure of the logic of these diagrams.

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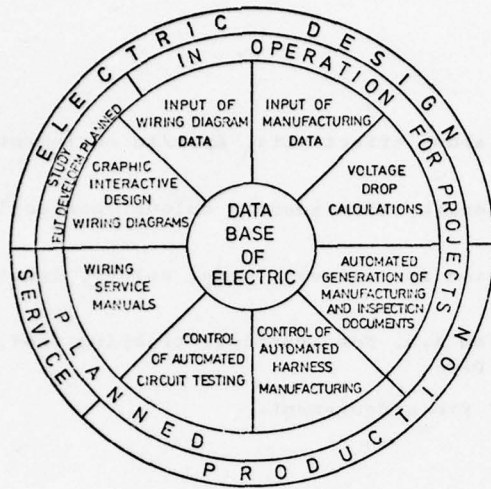


FIG.1 CAD AREA IN ELECTRICS

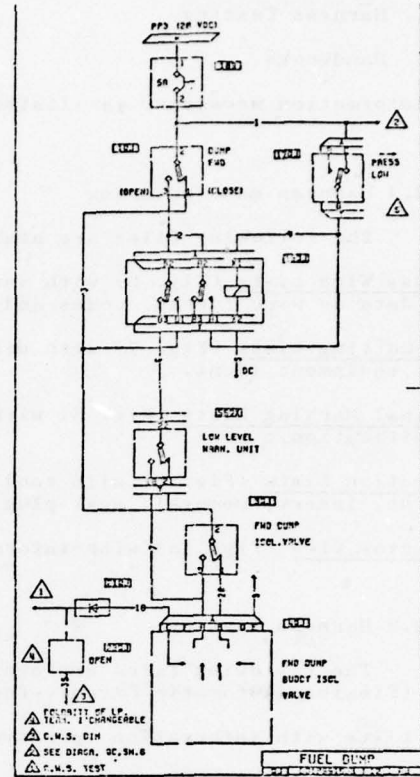


FIG.2 CIRCUIT DIAGRAM

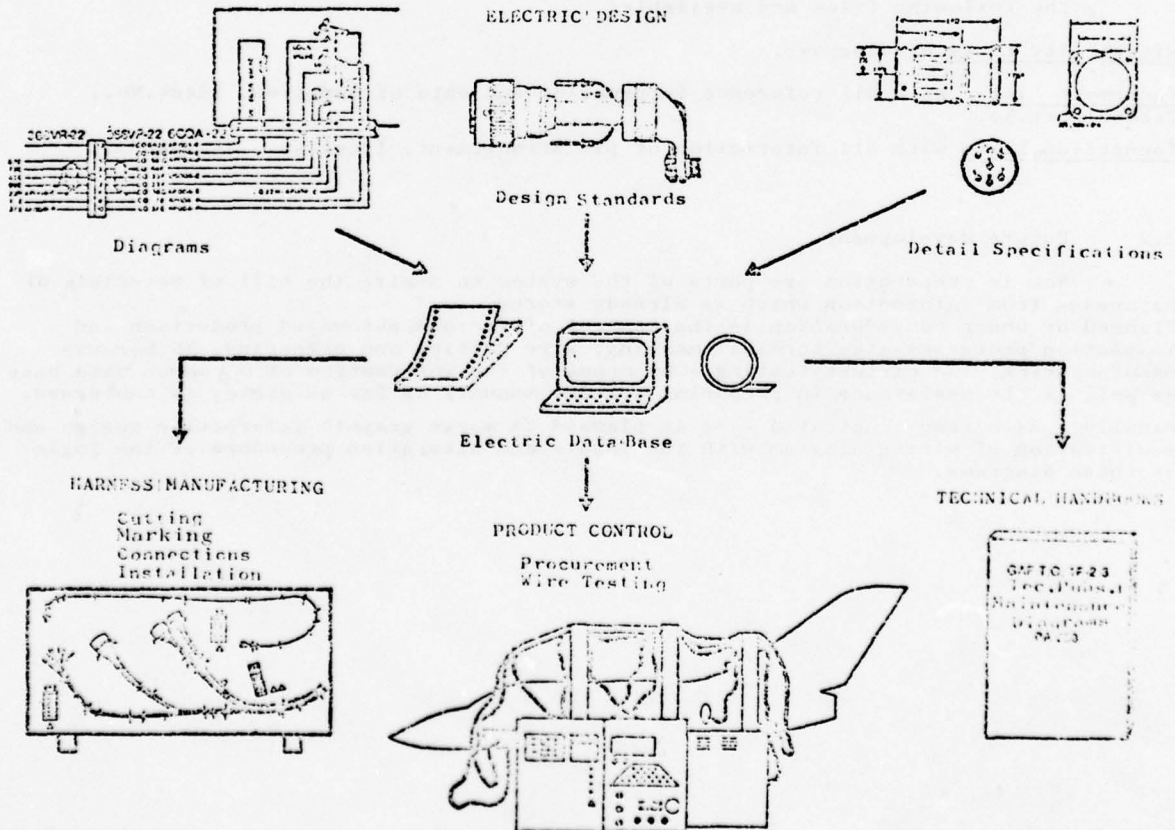


FIG.3 ELEK - SYSTEM IN OPERATION



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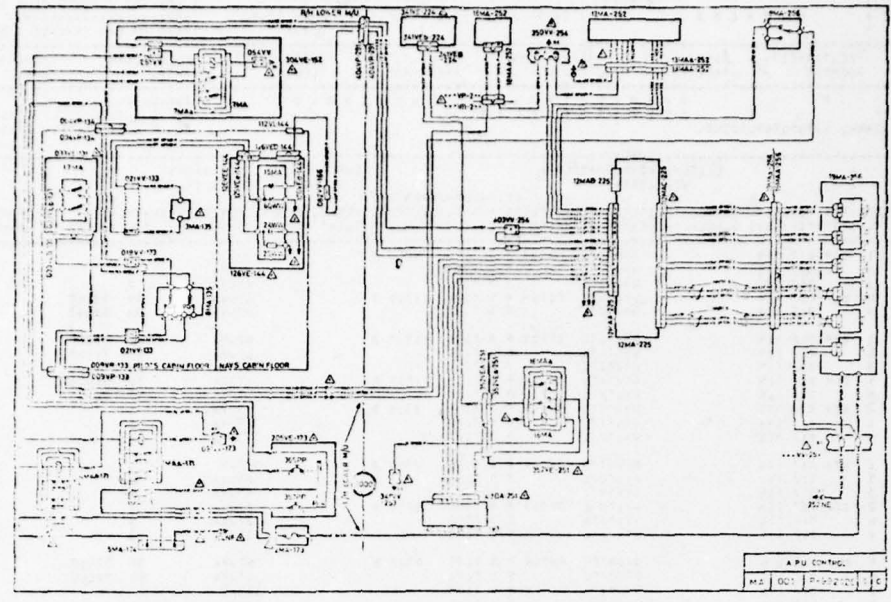


FIG.4 WIRING DIAGRAM

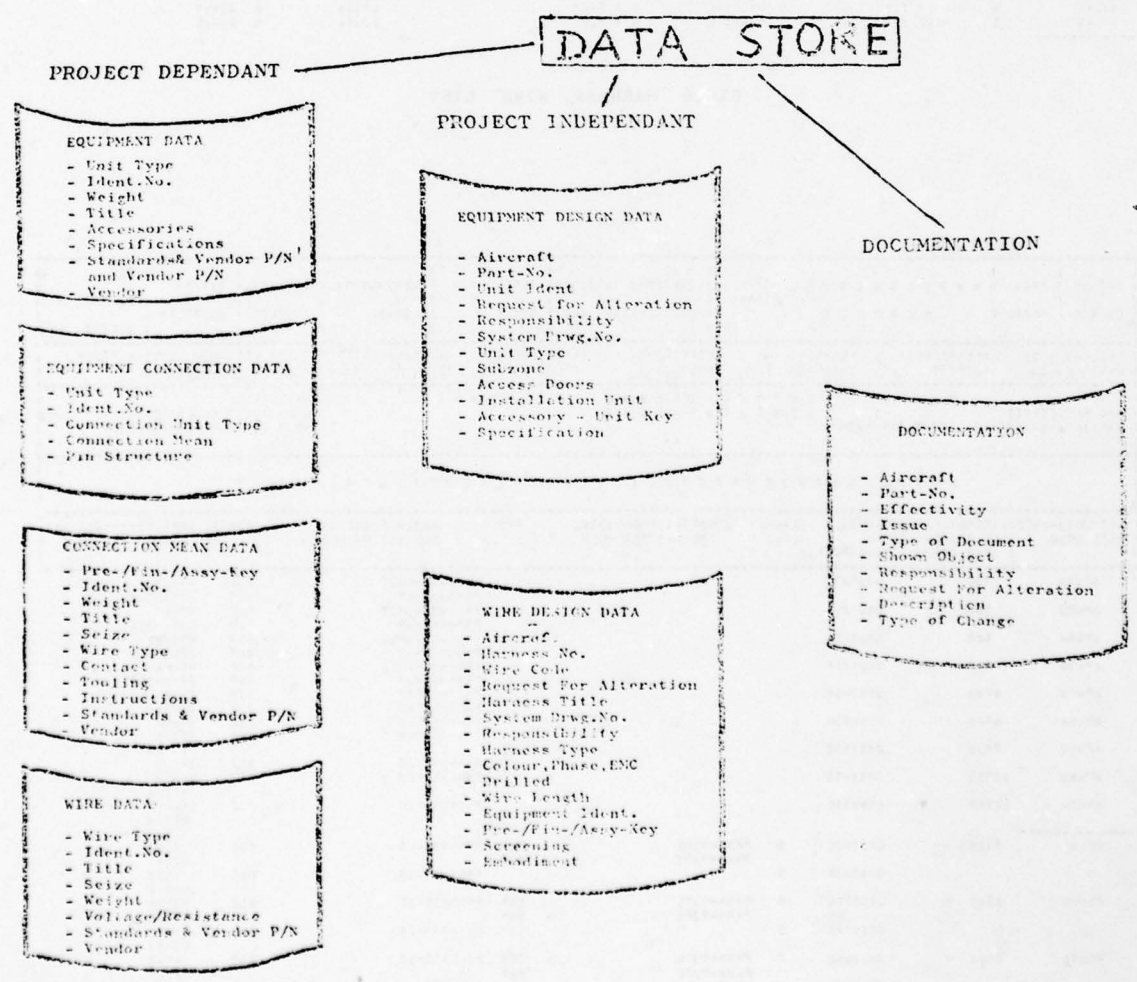


FIG.5 STORED DATA GROUPS

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2RNR 2. BATCH/2. BATCH ONLY								
YON ORHALT	LEITUNGS-INFORMATION	DUERCHFUHRUNG	NACH GERAT	REMERKUNGEN				
FROM EQUIPMENT	WIRE-DATA	WIRE	TO EQUIPMENT	REMARKS				
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IDENT	TPM	IPR	IN	IN				
374YA	1 074	012 115	UX0080E	Q0004 R S TIMD	1750 S	414XA	2	
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374YA	9	012 115	UX0080E	R S TIME		674XA	36	50602
404YA	1 004	012 115	UX0069E	R0004 R S TIGX	11900 S	674XA	12	50602
404YA	5	012 115	UX0069E	R S TIGX		674XA	42	50602
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404YA	2 004	012 115	UX0071E	R0004 R S TIMA	1200 S	354XA	1	
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414YA	5	012 116	UX0074E	R S TIMC		414YA	4	
414YA	3	012 116	UX0075E	Y S TIMC		414YA	4	
414YA	2 074	012 116	UX0068E	Q0004 R S TIMD	1750 S	374YA	1	
414YA	6	012 116	UX0068E	R S TIMD		374YA	5	
414YA	4	012 116	UX0068E	Y S TIMD		374YA	3	
434YA	9 004	012 116	UX0076E	P0004 R S TIGZ	8300 S	674XA	37	50602
434YA	6	012 116	UX0076E	R S TIGZ		674XA	50	50602
434YA	1	012 116	UX0076E	R S TIMH		354YA	6	
434YA	5	012 116	UX0076E	Y S TIMH		354YA	6	
434YA	3	012 116	UX0077E	G S TIMH		414YA	5	
434YA	6	012 116	UX0078E	R S TIMC		414YA	5	
434YA	4	012 116	UX0078E	Y S TIMC		414YA	3	
614YA	1 004	012 116	UX0117E	R0004 R S TJGH	2700 S	394YA	5	50602
614YA	2	012 116	UX0117E	R S TJGH		674XA	1	50602
614YA	5	012 116	UX0118E	Y S TJGH		674XA	6	22415
614YA	3	012 116	UX0117E	G S TJGH		624XA	4	22415

FIG.6 HARNES WIRE LIST

MANUF	MPCA	KABELBUENDEL	ZNR/DRNG	INDEX	RFA/AUTHY.	Z-DIAGR.	DATE/DATE	ZL
CU 419	FE292	HARNES S	2369VB	BAUCR./ASSY 402	ISSUE	50602	13.09.78	BL/SMT 3
QZ. C-N	IFESTIGKEIT	IGEWICHT	IFERTIGUNG	IPROD. SICH.	IPROD. ASS.	INWARTBARKEIT	IKONSTR. LTR	IZEICHN. PRUEF.
	ISTHES	INEICHT	IPRODUKT	IPROD. ASS.	ILGG.	ILGG.	IAPP.	ILGG.
AVC EFFLCTIVITY		U B M H G G I A A A A A		V U L M Z H R X Y		XALLE/ALL		
VARIANT/VARIANT-NR.		1 1234567890123456		S T S T S T A B C S T		1RNR 1. BATCH/1. BATCH ONLY		
2RNR 2. BATCH/2. BATCH ONLY								
LEITUNGS-TYPE	LAENGE	LEITUNGS-KENNZ.	IFARML	VORBEREITUNGS-MITTEL	PRE	ANSCHLUSSMITTEL	FIN S1	GERATKENNZEICHEN
WIRE CODE	(MM)	(MM)	ILGL.	PREPARATION MEAN		CONNECTION MEAN	F1	EQUIPMENT IDENT
AP004	750	UX0123E				PAN6432-1520	002	450VX
AP004	750	UX0123F				PAN6432-1520	009	215VX301
AP004	800	UX0121E				PAN6431-09	409	450VX
AP004	800	UX0121F				PAN6432-1520	002	450VX
AP004	800	UX0121F				PAN6431-09	409	225VX302
AP004	800	UX0121F				PAN6432-1520	002	450VX
AP004	800	UX0121F				PAN6431-09	409	225VX302
AP004	800	UX0103H				PAN6450F20	302	367VX
AP004	800	UX0103H				PAN6450F20	302	367VX
AP004	700	UX0109E				PAN6450F20	302	367VX
AP004	11150	UX0109E				PAN6450F20	302	367VX
AP004	11150	UX0107E				PAN6450F20	302	367VX
PR004	7500	UX0062E	R	PAN64033E	004	PAN6433-13	012	30XA
PR004	7500	UX0062E	B	PAN64033E	004	PAN6433-13	012	670XA
PR004	8300	UX0078E	R	PAN64033E	004	PAN6433-13	012	30XA
PR004	8300	UX0078E	B	PAN64033E	004	PAN6433-13	012	670XA
PR004	8000	UX0066E	R	PAN64033E	004	PAN6433-13	012	30XA
PR004	8000	UX0066E	B	PAN64033E	004	PAN6433-13	012	670XA

FIG.7 WIRE CUTTING LIST

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MS9-UF CO 419	MPCA FE202	KABELBUENDEL HARNESSES	2389VB	ZNR/DWNG BAUGR./ASSY	A922399 402	INDEX ISSUE	B2	RFA/AUTHY. 50602	2-DIAGR. A992609	DAT/DATE 13.09.78	ML BL/SMT 4 STE/PG 2/7
REZ. D-N	EFFEKTIVKEIT EFFECTIVITY	IGENICHT IMIGHT	IGENICHT IMIGHT	IFERTIGUNG IPRODUCT	IFERTIGUNG IPRODUCT	IPROD,SICH. IPROD,ASS	IPROD,SICH. IPROD,ASS	INWARTBARKEIT ILNG.	INWARTBARKEIT ILNG.	KONSTR.LTR KONSTR.LTR	ZEICHN,PRUEF. ZEICHN,PRUEF.
	P			B B M M G G I I A A A A A		Y U L H Z W R X Y				XALLE/ALL	1ENUR 1,PATCH/1,PATCH ONLY 2ENUR 2,PATCH/2,PATCH ONLY
ENDMARKIERUNGSLISTE / TERMINAL-MARKING-LIST											

THS-MODELLE THS-MODELLE	FARBE COLOR	LÄNGE LENGTH	ENDMARKIERUNG/MARKING IDENT	ANZAHL NUMBER
PAN649200	GRÜN	38	330XA 2389VB	1
PAN649200	GRÜN	38	394VB 2389VB	1
PAN649200	GRÜN	38	0A0048E R 0A0049E B 0A0070F Y 0A0075F G	2
PAN649200	GRÜN	38	0X0098E R 0A0099E B 0A0100F Y 0A0101F G	1 47 1 24
PAN649200	GRÜN	38	0X0098E R 0A0099E B 0A0100F Y 0A0101E G	1 010 020 017 020
PAN649200	GRÜN	38	0X0050E R 0X0051F B 0X0052F Y 0X0112F G	2
PAN649200	GRÜN	38	0X0078E R 0X0079E B 0X0070F Y 0X0077F G	2

FIG.8 TERMINAL MARKING LIST

IMBB-UF	MPCA	ANSCHLUSSPLAN	4UFA	ZNR/DWNG	001P202046	KLAPPE	DATUM	23.06.77
FE 2421		CONNECTION LIST	S2235	INDEX/ISSUE	A1	ACCESS DOOR	DATE	
PAN-NR	SACH-NR/SUPPLIER PART NO		HERSTELLER/SUPPLIER					
PAN6432-1F1419SM	HM06E1419SM9298 PVX6-1419SM 6026-1419SM		DEUTSCH CANNON AMPHENOL					

WERKZEUGINFORMATIONEN / TOOL INFORMATION

CRIMPING TOOL M22520/1-01 & 1-02 (MS3191-4) /  
LOCATOR RED SEL 2/002-3/004-4/006 WIRE /  
INS./REMOVAL T. NAS1864,INS.IPEC /REM,IMHITE /  
SEAL PLUG PAN6432-1N20 /

CRIMPING TOOL  
LOCATOR  
INS./REMOVAL T.  
SEAL PLUG  
SPECIAL PIN

FIG.9 CONNECTION LIST

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MBB-UFIMRCAIFEZ42IDAT123.06.77  
-----  
1001IP2020461 A1 1 4UFA 1BL/SH1 2 1

A U S I C H T 1 / V I E W 1

IP I N I E M C I V B - N R I  
-----  
I M I N E - I M E N T I C U L T  
-----  
I N . S I Z E I S C H I 4 P I N I

I H E 23601 | | A | | I B E 23601  
IUF0016E | | | | IUF0017E |  
1002 | | | | 1002 |

I L P 43601 | | N | | I P E 23601 | I C E 23601  
IUF0003E | | | | IUF0008E | IUF0009E |  
1006 | | | | 1002 | 1002 |

I K P 43601 | | U | | V | | I R E 23601 | I D F 23601  
IUF0002F | | | | | IUF0009E | IUF0005E |  
1006 | | | | 1002 | 1002 |

I J L 23601 | | T | | I S E 23601 | I E E 23601  
IUF0012E | | | | IUF0010E | IUF0006F |  
1002 | | | | 1002 | 1002 |

I H E 23601 | | G | | I F E 23601  
IUF0011E | | | | IUF0007E |  
1002 | | | | 1002 |

FIG. 10 CONNECTOR VIEW

## AERITALIA POINT OF VIEW AND OBJECTIVES ON COMPUTER AIDED DESIGN

by M.Castagneri

AERITALIA - Tecnologia  
Corso Marche, 41  
10146 Torino (ITALY)Summary

A critical analysis is in course at AIT concerning the usage of computer aids in the design and manufacturing areas. The performance of hardware and software has considerably grown in the last fifteen years but their development followed different methodologies depending on various areas of interest. The purpose of the analysis is to define a guideline to improve and collect all the computer program features to build up a system administrating a unique data base to optimize flow times, manpower requirements and to increase cost benefits.

Introduction

Since 1960 AIT engineering specialists have used the computer for the definition by conics of longitudinal shapes of the external and of the major internal surfaces of aircraft. Using a cross section logic it was possible to extract from numerical computer models the profiles, defined per points, needed by the structural designers. In 1969 the Geometric Data Processing System (GDPS) was finalized. The system allows specialists to define, by means of a comprehensive user oriented language, bicubic and conic organized surfaces to be stored on a data base. The system, running on IBM computer, performs the extraction of information from these mathematical models such as intersects with planes, stringers and other surfaces. An automatic drafting method using a large flatbed GERBER plotter controlled offline by the GDPS, has been introduced in AIT during 1970; it gave the opportunity of shortening the flow times of the graphic representation of profiles obtained by intersecting the mathematical models of the surfaces.

AIT are currently studying the Computer Aided Design (CAD) area to obtain a cost reduction in the structural drawing production cutting also the flow times, achieving the capability of going over workload peaks with minimum human resources availability. This objective includes some very important implications concerning the Computer Aided Manufacturing (CAM) area.

The benefits derived by the usage of a common geometric data set in the structural drafting, numerical control (N/C) programming, tooling engineering and quality control activity, very often justify, as will be shown later, longer CAD times than those needed applying traditional methodologies.

The batch CAD/CAM

AIT, in the last four years, have been deeply involved in software improvements and in establishing operative procedures to allow engineering and manufacturing specialists to use CAD/CAM methodologies as a current tool.

The purpose is to achieve the capability of designing and drafting structural components using directly the electronic computing facilities and to store the numerical definitions, when approved by engineering, on a data base; at that moment the data become available to the manufacturing area.

To do that, a user oriented language is employed (i.e., Automatically Programmed Tool-APT) by means of which it is possible to define a bidimensional cutter path geometry, consisting of straight lines, circles, splines etc.

Since a drawing basically consists of a set of simple geometrically defined items, it is possible, using the APT language, to collect the geometric entities in which the drawing consists. With the APT, it is as possible to describe the sequence followed by a zero radius cutter, contouring the structural component geometry. Postprocessing the file output of the computed APT part program, a cutter location file is produced on magnetic or punched tape, which drives the GERBER automatic drafting machine.

Very often intersection profiles must be represented, or used as reference, in aeronautical structural drawings; employing APT software improvements performed at AIT, it is now possible, using a common data base, to manipulate directly in the APT part programs the GDPS extraction data.

The final drawings are stored on data base in two different forms:

- APT part programs used for automatic drafting
- Elementary geometric entities in canonical form, each one associated with a label.

The first data type permits repetitive automatic representation of conventional drawings and of those additional drawings implied in the downstream applications, as N/C programming and tooling engineering. In some cases the data of this type are directly used in the N/C programming (mainly to machine templates). In the same format are stored also the APT subprograms called MACROS, describing repetitive and/or parametric entities that may be recalled and inserted in different drawings.

The second data type allows user access to any geometric information, by referring to its symbolic name. These operations are performed for data extraction and N/C programming activities and also for making drawing changes.

The batch CAD/CAM methodologies applied at AIT, have shown some limits and inconveniences; the most significant are:

- The draftmen have to be trained in the usage of APT language, that is complex: approximately four months are required to train personnel.

- The basic bidimensional characteristics represent a heavy limit in the range of applications.
- Each conventional drawing has to be associated to an other schematic drawing, showing the labels of all the geometric entities. This additional drawing is called "data set supplement".
- Drawings must be completed by hand to insert dimensions, notes, list of materials, etc.
- The job turn around times are very high, due to the batch characteristics of the procedure. Improvements are possible by applying remote job entry (RJE) techniques.

#### The interactive CAD/CAM

To remove the above deficiencies it is necessary to increase the effectiveness of methodologies, involving more sophisticated hardware and software. The achievement of this goal is based on the following conditions:

- To be interactive
- To employ a simple, user oriented language, made reliable by the tutorial management provided dynamically by the software.
- To be capable of defining real three dimensions structural components.
- To access and interrogate directly the surface mathematical models.
- To make use of a unique data base for every application.

AIT, to follow the growth in this field of other european Companies with in-house software developments, considered necessary to support a peak request of highly skilled personnel manpower. Therefore it has been decided to purchase an Interactive Graphic System (IGS) provided by a specialized Firm. Several IGS have been evaluated, to verify their matching capabilities against the requirements, which were:

- Sufficient precision in computing (especially in the coordinate transformations).
- Output capability for the on and offline automatic drafting.
- Two, three and five axis cutter path definition capability.
- Automatic generation of the following outputs
  - labelling of geometric entities
  - APT source part programs
  - APT cutter location file to be postprocessed
- Possibility of interfacing the IBM host computer with compatibility between the stand alone and the central data bases.
- Availability of a standard programming language, better if FORTRAN, for the development of user sized software.
- Possibility of inputting APT source part programs coming from batch CAD/CAM to complete the graphic definition and to allow interactive N/C programming.

Other points of interest related to the IGS capabilities were:

- Evaluation of weights and moments of inertia
- Structural analysis
- Finite element modelling

The criteria on the basis of which only stand alone IGS configurations have been considered were not dependent by a free choice, rather by what the market of IGS was offering in terms of performance. Using the results of the AIT evaluation an IGS, that closely fits the requirements, has been selected and ordered.

The present effort of the supplying Firm in the maintenance and in the improvement of software packages and the availability of FORTRAN language to personalize the system performance, represent reliable bases to cover the AIT necessities.

The IGS, however, must not be employed in the whole set of applications instead of batch CAD/CAM and conventional methodologies.

The structural component candidates have to be chosen and classified taking into account cost and time benefits using the IGS.

The below mentioned conditions are, at AIT, the guidelines to select the items to be worked by IGS:

- Simple parts avoiding long response time of the operator to the system.
- The definition of a family of similar structural components.
- The repeativity of the same detail or standard in the component or family of components definition.
- When a detail or standard is definable in parametric form and used very often in the component or family of components definition.
- When a definition needs input data previously stored on data base.
- When the output of a definition must be stored on data base to be used in the downstream applications.
- In the 3-D kinematics analysis.
- In the 3-D gaps, overlaps and interference analysis.

For the cost benefits evaluation, using the IGS, three different typical applications have been chosen :

- A - Part of a wing rib defined in its external shape by wing surface profiles and to be N/C machined (2,3 and 5 axis).

B - Inspection tool for the above item.

C - Set of similar wing flap ribs.

The amount of the needed manhours referred to the conventional methodology using batch CAD/CAM and interactive methodologies are reported in the table below:

	Conventional	CAD/CAM	
		batch	IGS
ITEM A			
Design	31.25	25.00	5.00
Drafting	12.50	18.75	2.50
	<u>43.75</u>	<u>43.75</u>	<u>7.50</u>
N/C programming	50.00	18.75	9.38
Data extract for Q/C	6.25	3.12	0.62
	<u>56.25</u>	<u>21.87</u>	<u>10.00</u>
	100.00	65.62	17.50
ITEM B			
Design	33.33	33.33	4.44
Drafting	66.67	22.22	4.44
	<u>100.00</u>	<u>55.55</u>	<u>8.88</u>
ITEM C			
Design	16.66		
Drafting	83.34	25.00	8.33
	<u>100.00</u>	<u>25.00</u>	<u>8.33</u>

Looking at the manhour comparison relative to item A, it appears that the same time is necessary in designing and drafting the component in both conventional and batch CAD/CAM methodologies; the second solution should however be chosen, taking in to account the cost savings in the manufacturing area. Concerning the flow time benefits derived by the usage of the batch CAD/CAM an average 20 percent savings have been found.

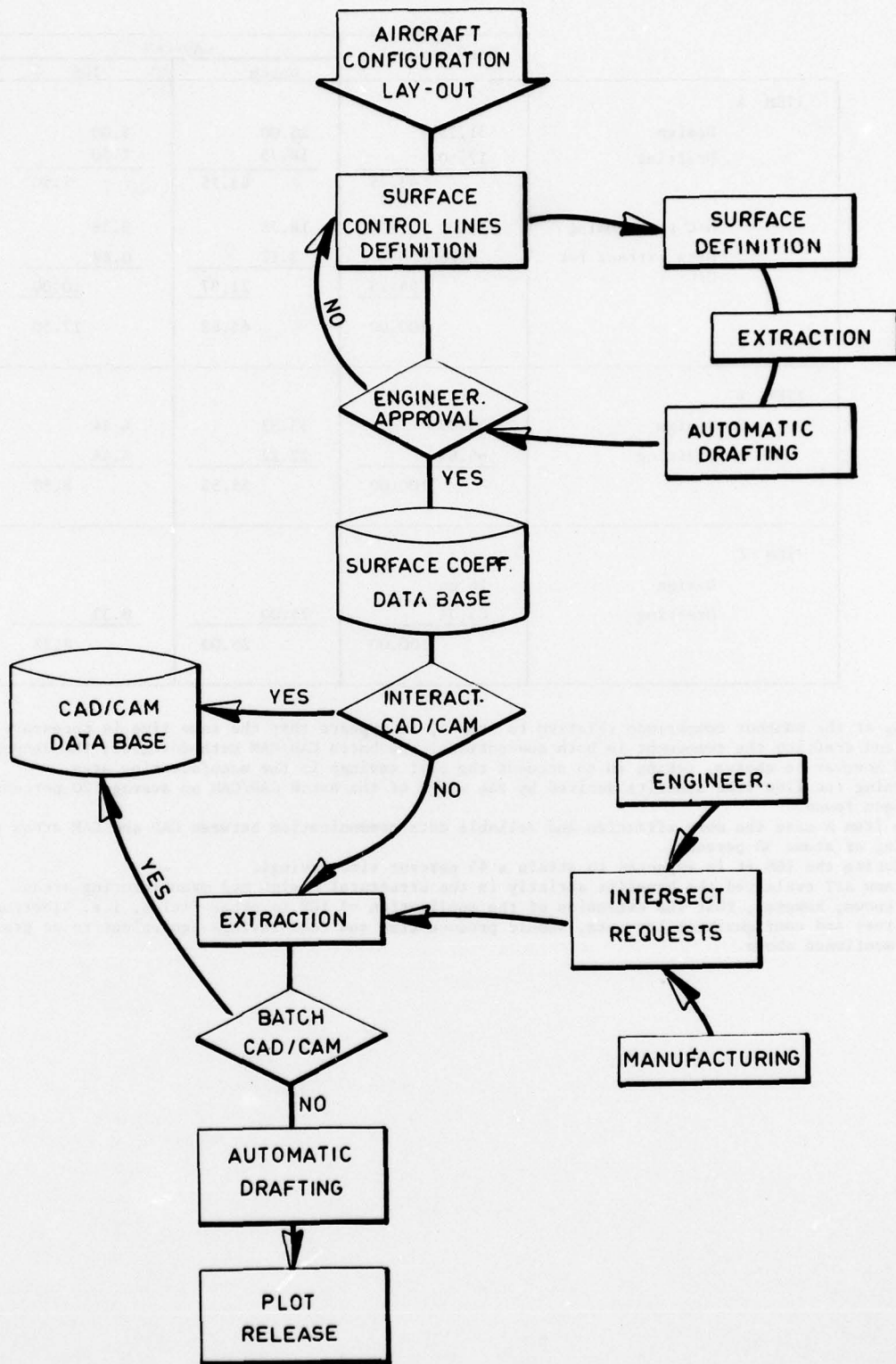
In the item A case the more effective and reliable data communication between CAD and CAM areas provides a saving of about 30 percent.

Introducing the IGS it is expected to attain a 45 percent time savings.

Up to now ALT evaluated the benefits strictly in the structural design and manufacturing areas.

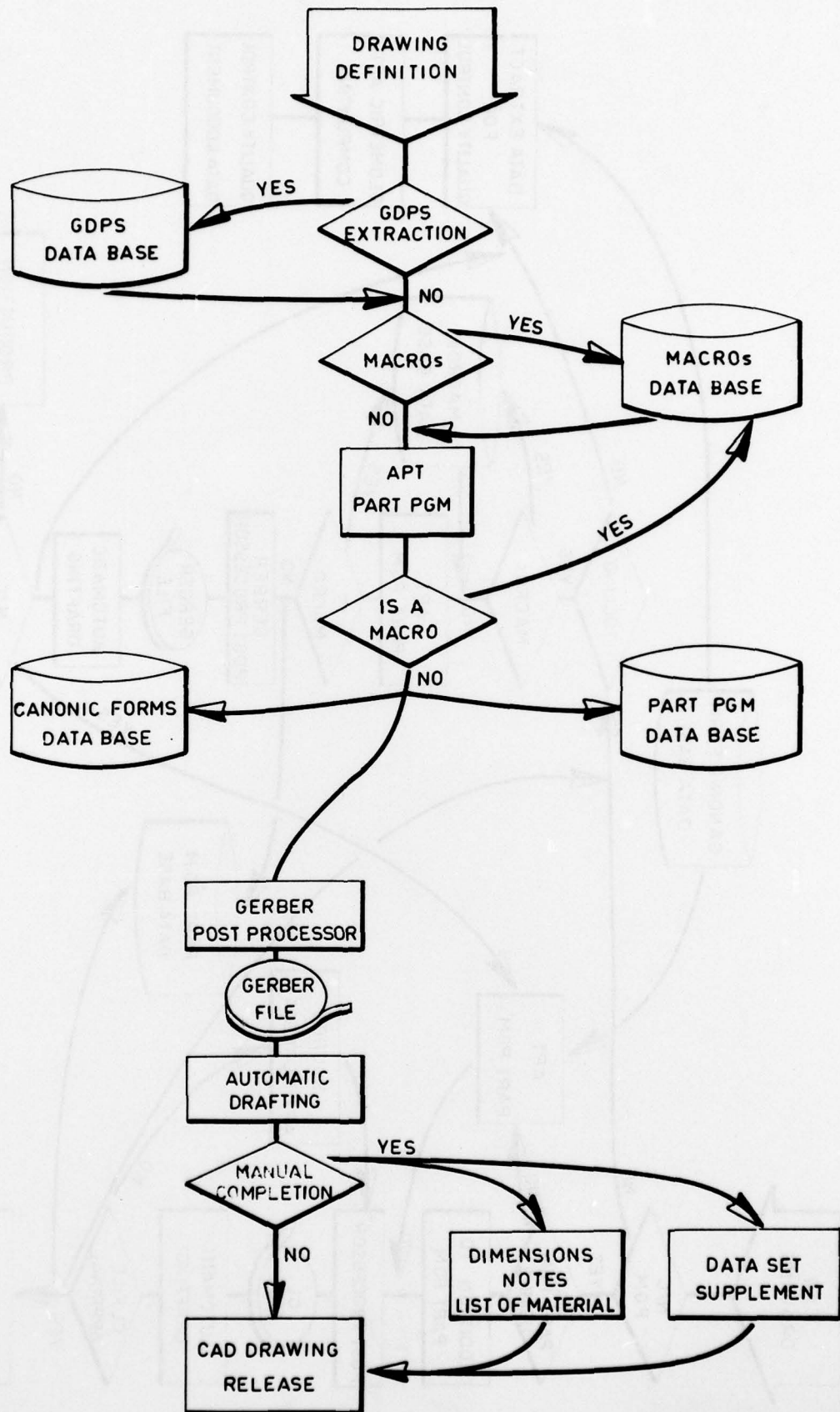
It is known, however, that the extension of the application of IGS to other fields, i.e. electronics, wiring, fuel and configuration lay-outs, should produce time and cost savings equivalent to or greater than those mentioned above.

## GDPS APPLICATION

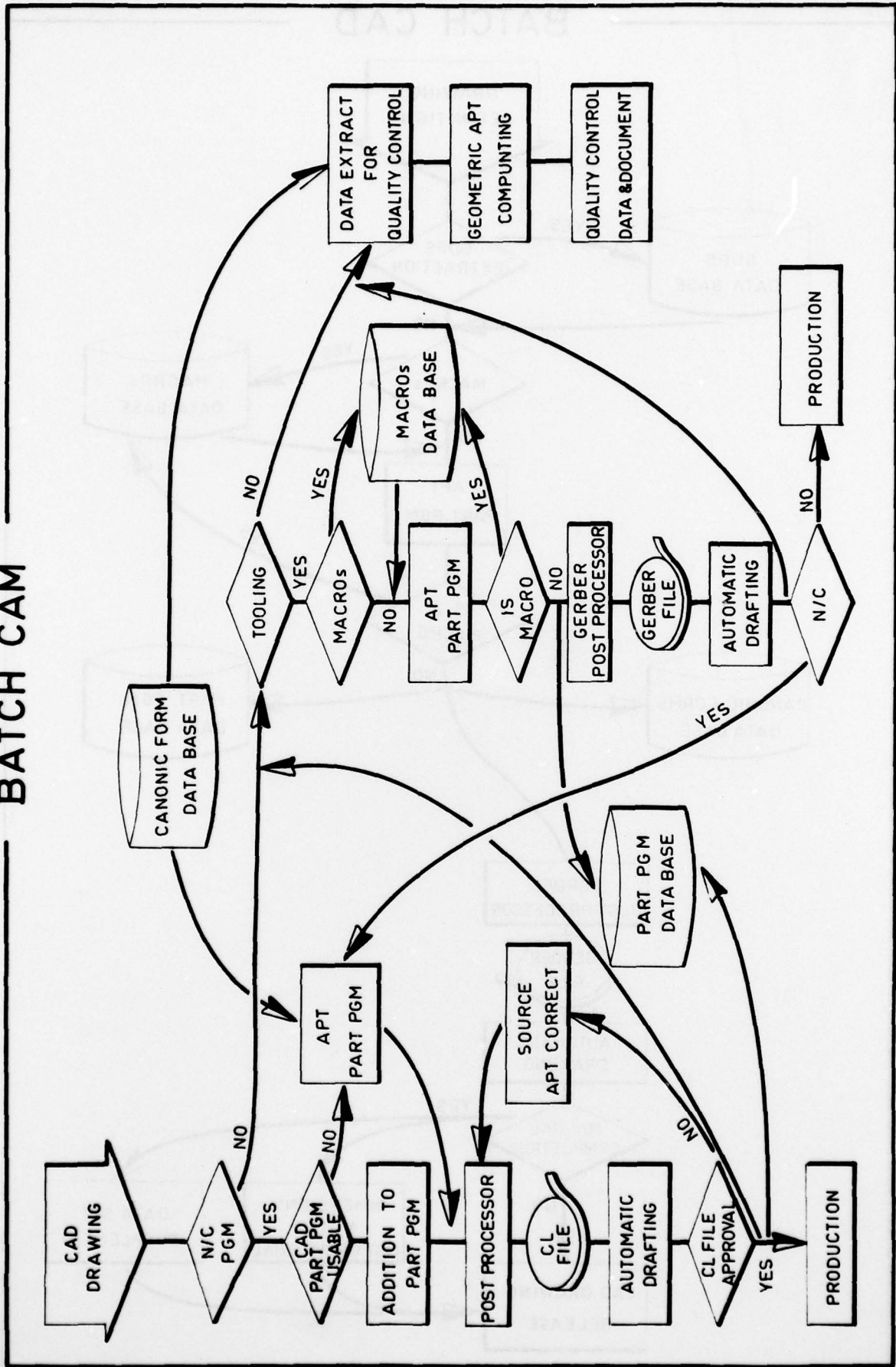




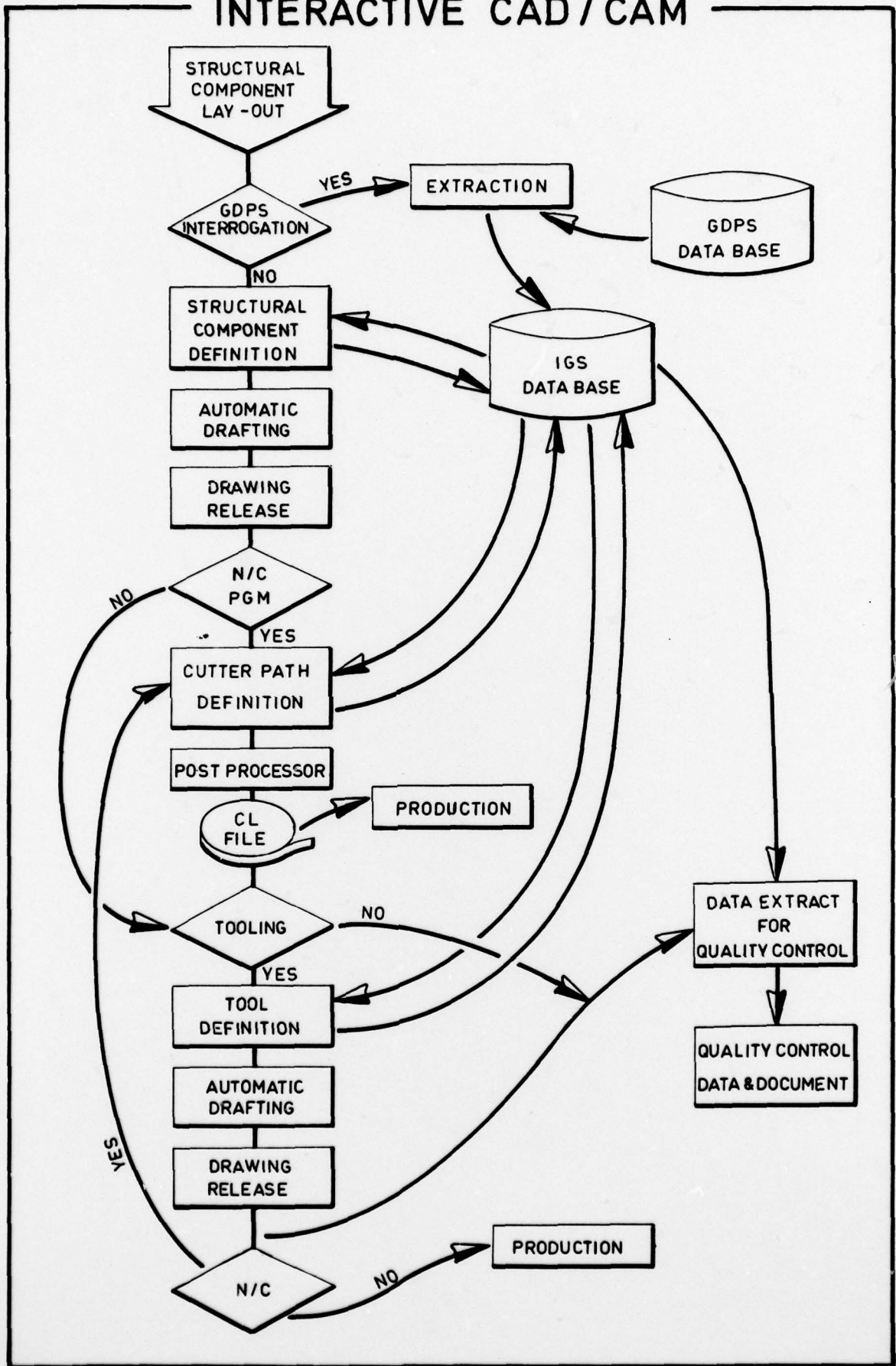
# BATCH CAD



# BATCH CAM



# INTERACTIVE CAD/CAM



## A DISCUSSION OF THE PRODUCTION DESIGN OFFICE BENEFITS OF C.A.D.

by

L.H. DYSON

British Aerospace  
Weybridge - Bristol Division  
Filton - U.K.

The generation of complex surfaces are just one of the computerised manufacturing aids that can be integrated into C.A.D. systems.

The mathematical description of a product is the foundation for CAD/CAM, its introduction must initially match the inertia of the existing organisation, and be seen to integrate into the manufacturing disciplines of a production environment where lead time savings will be giving the greatest cost savings. The cost to design of producing data for manufacturing may be increased, or at best only marginally less than the earlier less sophisticated approach.

Today the designer of complicated and sophisticated parts of an aircraft is no longer restricted to the two dimensional descriptive drawing of the past. The three dimensional graphic computerised systems now in regular use allow surfaces to be defined using a variety of geometric entities, as a model. Once defined section cuts can be taken through this model to determine the section properties, slopes, curvatures and volumes of the solid. The model can be viewed from any angle or in any designated axes and the interrogations related to any other axes or viewpoint.

This model is stored in a common database as the interface between C.A.D. and C.A.M. and provides a single source of geometric data and using various computer aided techniques is accessed by all other engineering disciplines. A major problem in aerospace engineering is how to minimise the number of interface problems, and those recording systems that allow engineers to know what other engineers are using could affect the efficiency and the standard of the product process, particularly in view of the trend towards project sharing. The effective integration of C.A.D. and C.A.M. therefore requires an effort to bridge the traditional gap between production and design but at a rate which will allow the changes to match the inertia of the existing disciplines, the acceleration given to the introduction of new techniques of such a complex and widespread nature are a function of social acceptance, manufacturing programmes and available resources.

Traditionally, investment has been developing C.A.M. and only in recent years has it moved into Design. I believe this reluctance to generate C.A.D. resulted from the fact that management were told how much financial and manhours saving was involved, but overall costs were constantly rising. This created a credibility gap.

The costs of developing C.A.D. are high in aerospace and using the traditional costing methods may not appear to be cost effective, as most visible savings are in the data for manufacture giving production lead time savings, which it is true may reflect a varying cost saving according to the critical path analysis of the product. It is therefore essential that a combined design and production cost analysis is used to bridge the traditional design office and production costing gap.

The manhour savings resulting from C.A.D. vary considerably according to the activities. The area of conceptual design uses a scarce resource, the creative individual, and the potential return for increased creativity is very great, the savings are not in the average engineers time, but in the expansion of the creative mans sphers of influence. The return from computer systems in the conceptual design phase is not likely to result in lower costs, but will result in improved designs that provide a better position for the company in competition for new development and production contracts, less time spent in non-creative tasks presumably means more resources for creative tasks. Estimates for the amount of engineering time spent on non-creative tasks go as high as 70 - 90%.

In individual cases, design costs can be reduced, design and product performance improved, productivity enhanced and lead time for design of prototypes, pre-production and production reduced.

These gains result both from improved efficiency within each phase and from the fact that the output from the process supporting one design phase is used as input to the next phase, this ability to cascade computer systems are of the greatest significance.

Surface definition is part of the process of defining an object or part of an object for evaluation and manufacture. Evaluation implies that information must be presented which will cause the object to be accepted or modified. Evaluation critia are complex, being some combination of such tangible or intangible entities as cost, technical performance, and of manufacture appearance and touch. Evaluation implies change and is the ideal situation, changes in the evaluation data may result in the definition of a satisfactory object. This condition is normally fulfilled in the engineering world by specifying critical data, drawing critical sections and specifying machining operations and leaving skilled craftsmen such as pattern makers, and tin smiths, to interpret the drawings and produce the final shape.

Corresponding techniques do not exist in the surface definition techniques currently available. The only acceptable alternatives are that -

- (a) the surface is defined by the minimum data.
- (b) there is an easily understood relationship between changes in the surface definition data i.e. surfaces must be easily and surely modified to obtain the evaluation data.

Physical bodies are usually composed of simple bodies faired together. The present mathematical surface definition techniques are such that individual bodies can be defined by one or more of the existing methods. The definition of a fairing between the bodies is not so easily accomplished and the inclusion of features within a single surface may prove to be impossible.

Figure 1 is basically composed of a straight line generated fin and tailplane, some fairing lines, and a lamp recess.

Almost any of the existing methods of surface definition could define the fin and tailplane separately with very little effort, a fairing shape could probably be established with difficulty in most of the systems. The fairing would, however, probably violate some conditions of continuity, surface displacement, shape and curvature at the junction of the fairing. The inclusion of the lamp feature could present even greater difficulties and it would probably not be difficult to construct relatively simple looking features which would defeat any or all of the methods.

The inclusion of the lamp recess together with the local modification of the surface in this region would probably defeat all currently available systems. A reasonable starting point would therefore be to assume that the complete definition of objects is, whether necessary or not, at this point in time, impossible. Let us now illustrate the source of some of the surface definition problems by considering the definition of the surfaces describing the tail plane.

The fin and tailplane main portion are symmetrical bodies and can be defined by the external curve. The numerical definition is readily accomplished by a mesh of points. The fairing between the fin and the tailplane would present a more difficult problem because, although its shape is probably established by sections and by eye, it is more difficult to visualise, the resultant surface and the criteria on which a design is accepted is obscure. The conventional procedure for designing the fairing might well be that a drawing is produced from which a model is made. The model will be fashioned until it is acceptable and this will then form the basis of subsequent design and manufacture.

Some of the considerations that would have to be made are :

1. What points are chosen to represent the shape? since the shape determines the points to be chosen!
2. Should the total body be subdivided into more than one surface? if so, will continuity conditions be violated at the joints.
3. How is it to be subdivided? does part of the body have to be included in the fairing to obtain a satisfactory shape?
4. Is it necessary to redefine the fin or tailplane to eliminate portions which do not exist, or are duplicated on the fairing, will this redefinition of the body involve further overdefinition and if so, how will this data be generated.
5. When the complete fin/tailplane/fairing have been generated what visualisation procedure is to be adopted to ensure that it is acceptable?

If satisfactory answers to these questions cannot be found there will be no point in proceeding further with a numerical definition.

The facilities available within a surface definition package play an important role in the way in which surfaces are subdivided. The provision and use of such facilities will cause few problems when applied to bodies defined by single surface. Considerable difficulties may, however, be encountered if surfaces are subdivided into independantly defined areas, and impossible situations may be introduced if objects are defined by overlapping areas. If facilities are not available to deal with these situations the subdivision of the surface becomes a compromise between the mathematical method of interpolation and the facilities available. A further conflict of this nature will inevitably lead to over definition, but may also in some cases prove fatal to the use of the particular system.

It would appear therefore, that as a general principle the surface definition package should be closely associated with the standard package used for the production of drawing and manufacturing information. If this is done, then the use of numerically defined surfaces will follow the normal engineering process in which objects are defined by both the information on the drawing and the production process.

Cascading from the surface modelling technique to the production of detail drawings is moving towards the activity where there are cost savings. When the model interrogation is used as input towards the basic detail design where design draughting man hours savings approaching 60% on some designs. Design Office overall costs will not however, necessarily reduce at this stage. Further downstream the jig and tool offices and manufacturing processes may make cost and manhours saving approaching 60%.

Figures 3 and 3A give some estimated savings of direct costs and manhour savings of C.A.D. against traditional methods of operation, however, load time financial savings are not indicated because of the aforementioned problem of assigning values to them. The savings in manhours can be 60% in addition to those shown. It has become evident that computer-aided design, when fully integrated into Aerospace Companies, will require data banks and a volume of data search operations beyond the widest expectations in other computer applications - and that computer-aided design can easily justify the cost of equipment. For instance, to describe the active and reserve fleet ships of the American navy to the level of individual repair parts for all repairable equipment approximately 200 million computer words. It has been estimated that 10 times this number of words, 2 billion, will be required during the latter stages of computer-aided design of an aircraft carrier and that the cost benefit for a single carrier could justify the computer facility, including buildings and ground. This is consistent in terms of computer requirements with General Motors experience, which is the only industrial system experience sufficiently advanced in operational use to provide significant comparison.

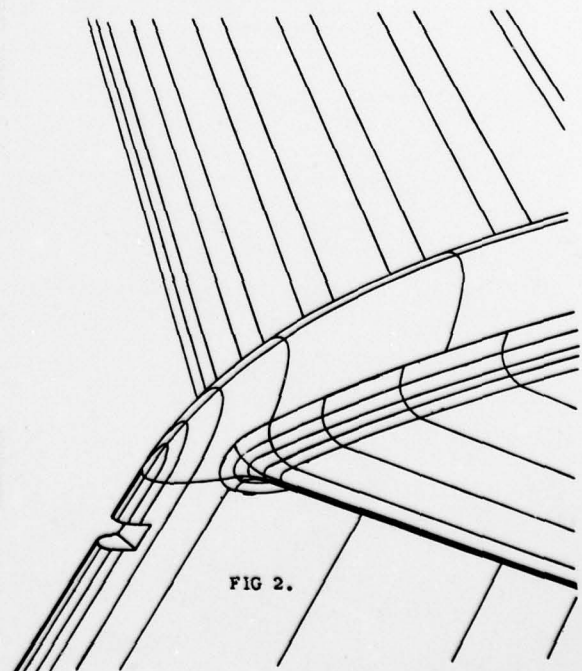
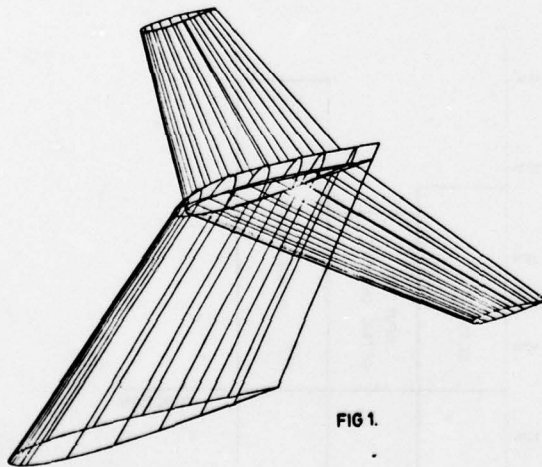
Long range, high speed transmission of great amounts of graphic information, important in computer-aided design and to technical data management, is not economically practical today. Neither is general use of rapid-access storage of 2 billion words. There is promise that both will be practical in the near future.

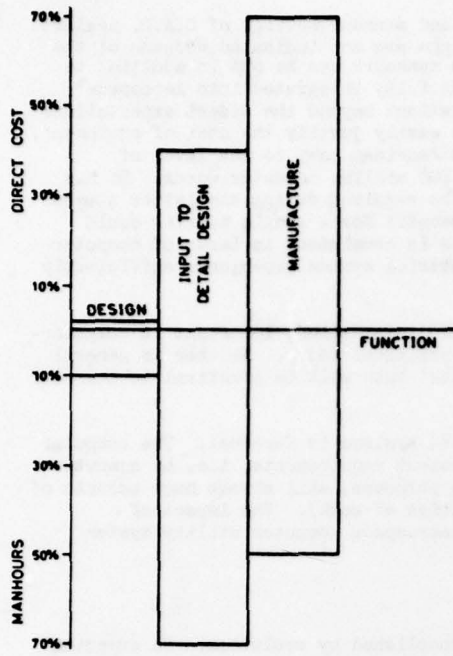
Technical data management today that does not embrace automated systems is farcical. The computer facilities of the future are almost certain to be shaped by the greatest requirements, i.e. by computer-aided design. These massive facilities, when not in use for design purposes, will absorb huge amounts of other work. (This is not meant to imply anything concerning priorities of work). The impact of computer-aided design needs upon what will probably some day be an aerospace computer utility system should not be overlooked.

#### In Summary

Wide application of C.A.D. will be a long range programme accomplished by evolution. To expedite this evolution great emphasis should be placed on the education of computer orientated engineers in the engineering colleges and universities. Industry should be encouraged to collaborate with the educational institutions to expedite the development of engineers orientated at an early stage to this new design technology. Education in this new design discipline is a most urgent need. The educational transition can be compared to the magnitude of the task of changing from the imperial system to the metric system of measurement.

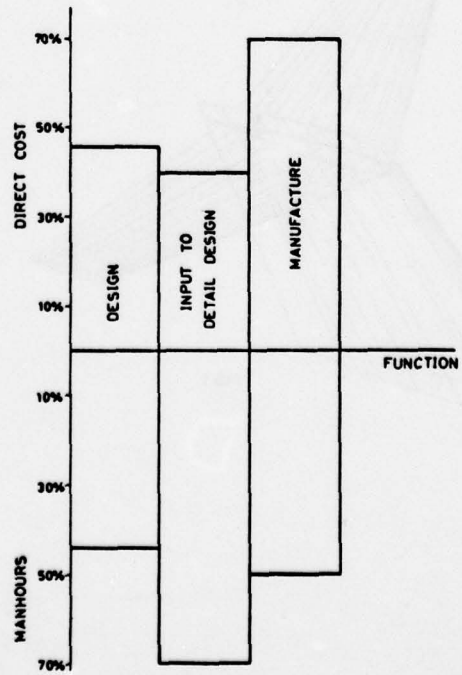
In general for process improvements affecting the early design phases, one should expect the industries emphasis to be on improving the effectiveness of the design and the production of drawings rather than on decreasing the cost of the design process. As one moves from design toward production, one should expect that the nature of the incentives influencing the rate of process innovation might place increasing emphasis on cost reduction especially where large production procurements are at stake.





ESTIMATED AVERAGE SAVINGS FOR NEW DESIGNS WITH PROFILES FOR CAD AGAINST TRADITIONAL METHODS

FIG. 3



ESTIMATED AVERAGE SAVINGS FOR MODIFIED DESIGNS WITH PROFILES FOR CAD AGAINST TRADITIONAL METHODS

FIG. 3a

## SUMMARY OF DISCUSSION

by

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The discussions on papers presented during the specialists' meeting and reprinted in this report have been held both directly after each lecture and at the end of each session (I, II, III).

Discussions following each individual paper mainly consisted of questions concerning a clear understanding of the contents, and went into further details of each topic, whereas the discussions following the three sessions covered all lectures held in each session broadening the scene and giving an outlook on future possibilities.

The brief discussions following each paper as well as the more general discussions following the three sessions highlighted the topics given below:

- o Human aspects, human engineering, working-place (screen).  
 For the time being there is no consensus with respect to the working-time per day of one individual in front of the interactive screens. Opinions expressed reach from 2 hours to 8 hours per day, but 4 hours split into two sessions of 2 hours each, one in the morning and one in the afternoon, was found to be most practical. However, this point mainly depends upon and is influenced by mutually exclusive interests, as there is the individual working-place availability ratio (to be between 90 % and 100 % for highest convenience) and equipment efficiency of screen and computer, in particular if it is a stand-alone configuration.
- o Employment versus unemployment.  
 Under the aspect of raising effectivity by introducing CAD/CAM, the point was made whether or not the employment ratio would decrease, and if so, to what extent. Several comments were made that a decrease in employment is not to be expected, whereas more or less severe changes of work break-down structure and needed talents and skills will certainly take place. These changes to be expected need careful consideration by management, information of the employees concerned as soon as possible and training programmes for those who will have to change their jobs.
- o Effectivity  
 The question has been raised how much of the design output, mainly drawings, should be handled by computer. The answers given ranged from some 20 % up to 80 %, in fact the system is able to handle them all (100 %). In detail, it is a matter of acceptance by the individual designer involved as well as a design philosophy possibly given by the management.  
 Even though there are no precise figures or results of investigations available so far, drawing time itself can generally be cut; but it was well understood by all participants that besides this, the main impact is achievable downstream of the design process.
- o 2 D-/3 D-Systems
- o Data bases  
 It has been expressed that a need for a real 3 D-System exists. Some areas of primary interest are exploded views, perspective drawings, weight calculations, and so on, because the systems used now are mainly 2 D-Software-based outgrowths and are more or less of makeshift construction and therefore temporary tools. But all steps toward a 3 D-System lead to a very high degree of complexity - software-wise - which means high-cost development.  
 In connection with this, the data bases have to be regarded as well. It is worthwhile to add a data base system to an installed CAD-Software system, e.g. for standard parts; the only problem is to build it up, which also means an investment of money and manpower.

From the papers presented and the discussions that followed, the conclusion may be drawn that in many places in Europe remarkable steps in developing and introducing of CAD/CAM have been taken by companies on their own, each step involving a higher or lesser degree of commonality. Nevertheless, the level reached varies highly from an overall point of view.



There is no doubt about the need for this new Design Methodology as a multi-functional tool for decreasing lead times and cost as well. Despite this fact it has to be realized that a broad and genuine breakthrough has not taken place until now.

The software specialists seem to be well prepared to take the next steps ahead before the state of the art reached by now is fully adopted by the majority of the users who are just about to check the possibilities and potentials of this new design tool offered to them. (This statement is related to the European situation only.)

It is evident that software specialists are capable of developing right away a 3 D-System for instance. From the system development point of view this would be a logical procedure. Still open is the question whether or not this should really be done before the present state of the art has reached a broader application. At least careful guidance and close cooperation between software development and application (users ?) is strongly recommended to ensure a maximum of common objectives.

The discussion made it quite clear that the development and application of CAD-systems does not merely mean the creation and introduction of a new design method, but that complete rethinking of the whole design process including interface documentation and all kinds of cross links of information has to take place. This is still a need, and only to a very small extent already a fact.

The participants in the discussion emphasized the need of and the readiness for follow-on activities for which especially AGARD forms an outstanding platform because of its non-competitive status. Even though there is no definite direct follow-on activity as a result of this meeting, it has been broadly discussed.

On the occasion of these discussions it became quite obvious that several participants did not find themselves in an enviable situation: Everybody in his capacity of specialist liked to be frank and open in presentation and dialogue, whilst as a company-delegate he had to watch out keenly for legal barriers and restrictions with respect to competition.

Nevertheless it may be stated that a lot of bi- and trilateral contacts for a continuing exchange of ideas have been initiated during this meeting.

As a conclusion from this specialists' meeting it can be said that there is a broad area for possible future AGARD engagement provided that careful attention is given to avoid collision with activities already started, as e.g. with AECMA, CAMJ a.s.o. as well as with company internal interests like competition. The following topics are specified as a proposal for future work under this understanding and put forward for discussion.

1. The common development of a specification for a realistic 3 D-System related to the users' requirements.  
It seems that in various places activities are just being started. It could be of interest as well as of assistance to those people engaged in this work to get an international crosscheck.
2. Common development of an interface specification to enable data transfer between design offices of different nations and/or companies.  
This should be done without touching the already existing company internal basic systems and/or individual modules.
3. Common development of a specification for design-specific data bases (e.g. standards).  
Everybody needs it and every one grudges the expense. This could perhaps be overcome by sharing the job between a number of partners and putting together the results.

The results of all these proposals could well be a further AGARD-contribution to higher commonality within NATO-Countries in this field.

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