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THE APPLICATION OF MODERN COMPUTER TECHNIQUES TO AERONAUTICAL DESIGN PROBLEMS

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COMPUTER AIDED DESIGN IN THE AIRCRAFT INDUSTRY

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Abstract

Computer Aided Design as an aid to the designer/draughtsman is discussed in this paper. Progress at BAC (Weybridge) on the preparation of a Data Bank holding the geometric description of piece parts is outlined. The means for capturing the data is described along with ideas as to how the data should be used down-stream in the manufacturing areas. A graphics Visual Display Unit is an essential tool in the idea and some experiences with a General Purpose Visual Display Unit, in the general scientific computing environment, are described.

Introduction

Computers have been used in the Design process in the aircraft industry since about 1955. Their use is widespread and the cost becomes a significant part of the total design running cost, namely about 5%.

In the past era the uses have been as an aid to technical analysis, reduction of test data, administration and more recently some form of process control as in controlling test rigs, wind tunnels or Numerical Control tools (Figure 1).

A notable omission has been the work of the designer/draughtsman - the computer has in the past fifteen years made no impact on his work at all and the designer/draughtsman has hardly needed to know even of the existance of the computer, this the most powerful tool of the 20th century.

The reasons are not far to seek : the work of the drawing office, in the aircraft industry at least, proceeds through the medium of pictures - drawings in fact - but in the fifteen years the computer has been developed to do arithmetic, handle lists, manipulate files and has had no picture handling ability (Figure 2).

Times change : there is now a variety of ways in which a computer can produce pictures as output and a (lesser) variety of ways in which a computer can accept pictures as input with the result that, for the first time since the computer appeared on the scene, the designer/draughtsman can be aided.

The words Computer Aided Design can mean all things to all men - in this talk it means the new ability of the computer to aid the designer/draughtsman. Insomuch as the purpose of the designer/draughtsman is to create drawings - as things are at present - and these drawings represent parts to be made and assembled by manufacturing, so does Computer Aided Design get involved in the production and inspection processes. Any techniques or computer systems aimed at aiding the designer/draughtsman must take note of the needs of down-stream activities and these may in time come to alter the traditional outlooks of the designer. Certainly the traditional conflicts between Departments appear in sharper relief as various C.A.D. schemes are proposed and introduced. C.A.D. is then seen as a great leveller crossing the boundaries of the various Departments as a matter of necessity and reconciling the needs in a comprehensive manner.

The only parallel to this has been in the computer application to Data Processing, the pain and agony of which has been well publicised.

The Grand Design

In the modern aircraft there are some 65,000 drawings of separate piece parts to be produced. Subsequent variations lead to as many again.

The grand design is to bank in the computer's store the information contained on the drawing - both geometric and alphanumeric - in such a way that the design process itself is aided and, more importantly, that down-stream manufacturing processes are aided.

The grand design can be illustrated as in Figure 3.

The data bank is foreseen as holding the current design project, the current production project and perhaps one other, and as such may need to be 300 or 400 million words (24 bit say) of store.

It is expected that this store should be readily interrogateable by a great number of departments using conventional remote multi-access devices but that in addition there should be a remote visual display at many, if not all stations. The display is to serve the purpose of presenting a picture to the interrogater of the part which he has called up, appropriately annotated so that reference can be made in detail to its features.

Typically for example an inspector might wish to know the width of a flange on a certain part. He goes to his console, calls up the drawing, is presented with a picture like say in Figure 4, and keys in the request "L.68; L.1057; D?" for example, which causes the response "2.57 ins." being the distance between lines 68 and 1057 which he sees on the drawing.

Such a data bank, carrying all the design information, must be able to communicate with the other production control and administration systems. Only a small part of the information, probably part no., assembly data, issue number and material, are all that needs to be passed across.

The significance of this grand design is far reaching. It may for example mean that the conventional drawing - blue-print - after a life of 150 years dies away. Or it may be that a microfilm direct from the data bank is substituted but as a legal document only. It could lead to a concept where important key dimensions are declared at design time and these are automatically computer produced and passed across to manufacturing as a special document, a copy of which is given to Inspection for them to 'fill in', these being the only dimensions that really matter.

Whilst this grand design is basically conceived around parts and their design and manufacture, it could be that assembly drawings are no longer needed being made on request from a multi-access console by the computer from parts information in the data bank; that is, parts could be 'assembled' on a visual display and the display rotated or sectioned as needed at the instant.

So far at BAC (Weybridge), and elsewhere within BAC, attention has been focussed on the problem of capturing the design information and getting it conveniently into a data bank. However, pressure from Numerical Control, Jig and Tool Design and Inspection have led to the creation of a number of special procedures which have influenced the work.

Little has been done on the file handling aspects.

The multi-access and visual display aspects are expected to lean heavily on experience gained in their use in the more conventional analytical work.

Incentives

Perhaps the biggest immediate incentive has arisen from the rapid growth in Numerical Control machining and its expected continued growth and extension to other areas, e.g. inspection. Part programming is a bottle-neck and some 30% of the effort expended by the part programmer goes into learning and redefining the geometry. This is sheer duplication of the designer/draughtsman's work. Its complete elimination would flow from the C.A.D. venture described and the moneys saved would offset a significant part of the first cost of the system.

Next in line, is the incentive to give help to Inspection who, having equipped themselves with read-out inspection machines (Figure 5) giving x - y co-ordinates of probed features relative to an x - y axis system, cannot convince the designer/draughtsman to dimension his drawings to suit. He is never likely so to do! But it is not difficult to enable the x - y co-ordinates to be produced from the data bank.

In summary, the incentives mostly come from all those down-stream, and they are many, who need to make use of the geometry and who continually perform a whole host of smallish calculations.

However, in attempting to meet this need it becomes apparent that an equal or greater gain can be obtained in the design area itself. For it transpires that in the detail design phases there is a considerable repetition of small items slightly changed, e.g. stringer cut-outs in frames and ribs, cleats between stringers and frames, rivet patterns, frames and ribs themselves, and these can be described once - as a macro say - and called up, with differing parameters, many times, (Figure 6).

On the wider issue however, it must be recognised that the more repetitive work becomes increasingly unpalatable to the new generations, who are educated to new standards, and it becomes increasingly difficult to man it. Such computer schemes often arrive in the nick of time to take over the work.

Some Detail

The earliest recognition of these pressures led to the production of the BAC Numerical Master Geometry scheme (N.M.G.) which exists in two versions, an ICL 1900 version at Weybridge and an IBM 360 version at Preston. This scheme affords means for designing and using the curved surfaces of the aircraft external shape. The Coon's parametric surface concept is used with the twist terms included. The corner data is produced from the generalised cubic spline which is used to fit the designer's basic guide-lines. A typical representation of an aircraft by N.M.G. patches is as in Figure 7. Parts of Concorde and Jaguar, the whole of MRCA and the whole of the (projected) BAC 3-11 are based on the N.M.G. scheme, which is now well established.

From this scheme can readily be extracted (or more properly, referenced) all the information, of this type, required for parts description, e.g. boundary lines having the external shape, surfaces of, or "parallel" to, the external curved surface, intersection lines of two curved surfaces. Such lines are needed, for example, in defining a frame's outside boundary which, in conjunction with the 'furnishing line' of a passenger transport defines the complete frame (Figure 8).

However, although a flying start to the design of such parts is obtained by extracting from the N.M.G. these lines and presenting them to the designer/draughtsman as automatically computer produced lines on paper, this is not the design proper.

The designer will now add to this information an enormous amount of detail, drawing and designing in assemblies and it is this detail, as well as the N.M.G. main lines which have to be put into the data bank. The detail, however, is mainly comprised of straight lines and circles and is thus simple in fundamental character.

To capture the information on parts implied on these assembly schemes BAC have chosen a system in which the draughtsman writes computer code directly. Assembly schemes will be passed to detail draughtsmen who instead of making a precise scaled drawing will code the part, perhaps making a sketch as they do so. The alternative of offering the assembly scheme to a drawings digitizer, e.g. the Ferranti A.D.E. reader is not excluded.

The language chosen at Weybridge to do this is Ferranti's (now Plessey Numerical Control)

PROFILEDATA to which considerable enhancement has been, and is expected to be made. At BAC (Preston) a similar line is being followed but currently APT is favoured as the defining language. PROFILEDATA is essentially a description of a two-dimensional pattern of lines : thickness and depth information has to be introduced separately. This is simple to do on parts which are "$2\frac{1}{2}$D" for PROFILEDATA is a $2\frac{1}{2}$D language. Even so, to date, the work that has been achieved has been mainly in describing separate views as in ordinary orthographic projections (Figure 9). A more comprehensive three dimensional description is being developed and ideas are being formulated for a fully three dimensional component description process.

Among the enhancements to PROFILEDATA found necessary to suit it as a parts description language are (Figure 10):-

Fillet Radii
Composite Curves
Symbolic Distances
Repeat Codes
Macro Facilities

An essential to any drawing scheme working off code is a means for visualising the code for checking purposes. In the interim between the past and the future, such visualisation is also needed for archival and legal purposes. The visualisation employed is a drawings post-processor - or drawing language - which takes PROFILEDATA as input along with pen driving information and outputs data for automatic drawing machines. This needs different facilities from the post-processors which drive cutters, e.g. dotted or chain line drawing, annotation, drawing surrounds and referencing grids, cross-hatching, etc. The Weybridge drawing post-processor known as G439 has been devised to be as terse as possible and to follow natural draughtsman's inclinations. A specimen is in Figure 11.

PROFILEDATA geometry works by defining infinite lines, whole circles, etc., and by computing the appropriate intersections and joins, called change points, to which are assigned names. One development of the scheme places these names in suitable spaces on the drawing. These same names, or their equivalent, are expected to be called up and displayed on the visual display and are the computer-conscious references for any interrogations.

It is at this stage, possibly, that information concerning the key dimensions can be added to aid in the inspection process but details have not been worked out. However, it is clear that, except for linking into the past and possibly for legal reasons, there need be no formal attention paid to dimensioning and dimension lines on any visualisation, for a simple interrogation will yield any dimension that is needed. Notwithstanding it has been deemed prudent to have available means for adding conventional dimensioning lines and symbols to any drawing visualisation.

Some Problems

The basic problem in any such scheme is 'customer acceptability'. This is best overcome by customer involvement and by adjusting the pace of development to that which can be assimilated comfortably.

On technical matters the organisation of a store of some 300 - 400 million words is a considerable problem. This needs an appropriate data structure whose overheads don't destroy its potential advantages but an access time - on first access - which can be measured in terms of seconds if not minutes. The access rate is not assessed but is probably considerably less than one every five minutes. A hierarchy of some kind would seem desirable but except for archival matters and breakdowns magnetic tape is unlikely to be valuable. Magnetic cards would seem very suitable.

On a detail front there are difficulties of knowing where to put annotation markings on drawing visualisations without their interfering with one another and obscuring other lines; in the problem of not knowing how sophisticated to make the input language in view of the task's being done by detail draughtsmen; there are problems of ensuring that the code is correct in a time scale quicker than allowed by accurate draughting machines operating averagely around 100 in. per minute (perhaps microfilm recorders answer this question); there are problems in handling dimensioning particularly in devising an algorithm for positioning the dimension symbols and annotation; and there are problems in defining and maintaining the legal masters (e.g. if the master is the computer's store, any real-world check works from some copy, or other manifestation, not the master).

At the moment we have firm ideas concerning parts description in a $2\frac{1}{2}$D mode only. Along with this goes the idea that a different pre-processor will be produced for different categories of parts, e.g. turned parts, flat or bent plate work parts, sculptured parts, etc. By 'pre-processor' is meant a procedure whereby the computer produces its own PROFILEDATA code from specially and conveniently arranged input data for the specified category of parts. In the near future there is the possibility of a more comprehensive 3D parts description language which, whilst it may still have variants for component classes, will work with 3D pieces like cylinders, cubes, parallelopipeds, cones.

There are philosophical problems which can be raised : e.g. is it sufficient for Inspection to inspect the store or a magnetic tape along with a periodic machine check for the inspection of parts made on Numerical Control machines.

Some Equipment

It is to be expected that the 'visualisation' equipment will play great prominence in this scheme.

Amongst these will be:-

Draughting machines of the flat bed type
Drum plotters
Microfilm recorders
Visual display units of the graphics type
Character displays

Of these, only the graphics visual display will be discussed.

For the purpose of the C.A.D. scheme outlined there is a prime requirement for visualisation of a part in a remote multi-access environment. In the first place this ensures that the right part is being referenced; secondly it enables the area of interest to be identified at a small scale and last it enables "windowing" on to the part of interest to identify the annotation of the features to be discussed. This is mainly a passive graphic system; interaction could take place through the tube by indicating features of the part with light pen or marker, but with satisfactory annotation this could as well or better be done through a keyboard. In this event a simple storage tube would suffice and would help to keep costs in check.

However, BAC have no experience of operating a storage tube but have had experience of using a fully interactive graphics display - the ICL 1830 - for about 18 months, although in the area of technical analysis in general rather than this aspect of C.A.D. in particular.

The ICL 1830 (Figure 12, a and b) is a fully interactive graphics display with light pen having a screen of usable area 10" x 10" which is connected to the ICL 1905F computer as a peripheral. It has the novel feature of having a repeater tube within it connected to a microfilm camera.

It has not proved simple to get a satisfactory flow of suitable problems to it or through it for a variety of reasons. It certainly has not earned its keep - but this is in common with almost all other experience.

Amongst the reasons for this are:-

1. Problems tend to grow in core requirement and there is insufficient core to spare. A special V.D.U. overlay scheme would circumvent this difficulty. 32K words is the current limit.

2. There is a tendency to explore problems having high interactivity but these are difficult and exacting to programme.

3. The device works in 'real-time'; therefore development of problems proceeds in real-time and compared with other computer activity this is slow.

4. Since the 1905F is saturated (640 hours per month) only some four hours per day can be spared for the 1830 which at 30 minutes per V.D.U. session means only eight persons get a shot once per day.

5. The 1830 system does not at the moment communicate with the batch system.

For these reasons, inter alia, problems with high interactivity such as are often discussed by other users have not made much progress

Such problems are N.C. cutting path description (as Lockheed's system, or GRAPPLE) or interactive structural analyses, e.g. of fuselage frames. Rather has there been success with problems which are weakly interactive and it may be that in the future the V.D.U. will be mostly used on such weakly interactive problems.

Amongst those explored at Weybridge are:-

a. Flutter analysis in which new speeds or altitudes can be selected in the light of the displayed damping at previous speeds (Figure 13).

b. Display of Coon's patches in which the significance of the data can be demonstrated and chosen data checked (Figure 14).

c. Display of files containing graphs or carpet-plots with interactive facilities for amending or correcting them (Figure 15).

d. Vision envelope display : in which a projected wind screen arrangement can be positioned interactively relative to an alterable nose fuselage shape and the vision envelope calculated and displayed against a standard for any chosen eye position. This is rather more interactive than the others (Figure 16, a, b and c).

e. Curve fitting test data, e.g. fitting circles to Kennedy - Pancu stability diagrams obtained from flight vibration tests (Figure 17, a and b).

f. "Instant Calcomp" : being a procedure for routing answers destined for drum plotting to the V.D.U. for viewing and recording on its microfilm recorder. This is only as useful as it is possible to beat the batch system and get such a problem on to the 1830 anyway.

There is always, with displays, the question of hard copy. The 1830 is especially well equipped with its microfilm recorder triggered by programme but even so the microfilm needs developing and this takes time. A single shot facility is available.

However, experience with this device in the general technical computing and C.A.D. environment is not discouraging in principle : once displays and the means for driving them remotely become available at about £5,000 per terminal including line charges, interfacing costs and shared satellite computer apportioned costs, they will be truly viable.

This V.D.U. experience is not particularly relevant to the C.A.D. venture forming the main substance of this paper but it serves to give confidence in the V.D.U. as a useful device.

Summary

In summary, apart from developing C.A.D. as an extension of technical analysis, BAC are exploring a variant of C.A.D. to aid the designer/draughtsman. It is planned to produce a data bank containing the information defining piece parts and to make suitable interrogations possible and convenient to a wide range of departments. An essential interrogation device will be a graphics tube probably a storage device. The time scale is likely to be of the order of five years.

- **Technical Analysis**
- **Test data reduction**
- **Administration**
- **Test-rig control**

FIG. 1. COMPUTER USAGES

- **Arithmetic**
- **File handling**
- **List processing**
- **PICTURE handling**

FIG. 2. COMPUTER CAPABILITIES

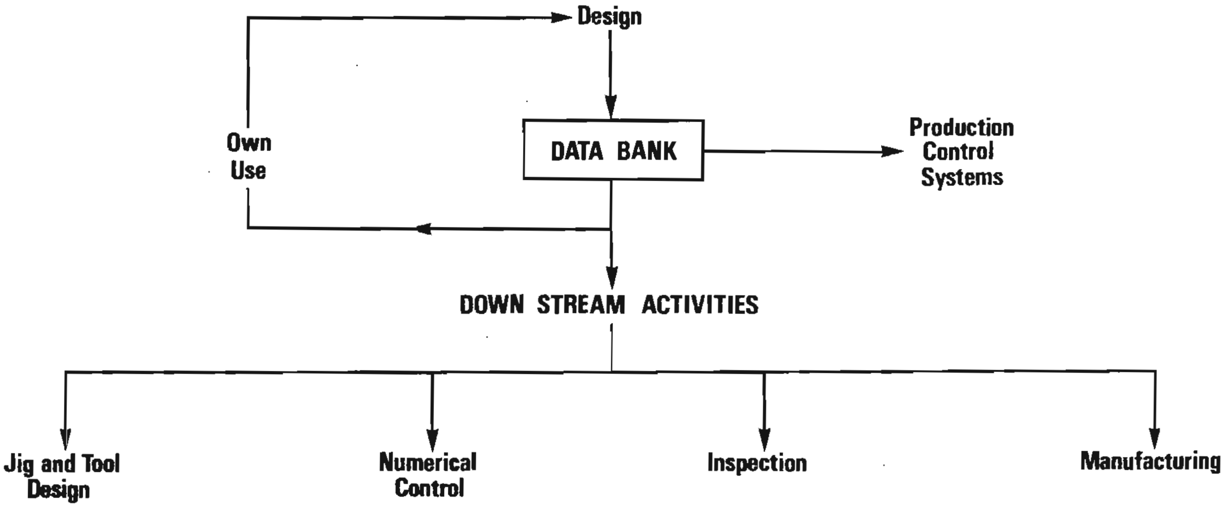


FIG. 3. THE GRAND DESIGN

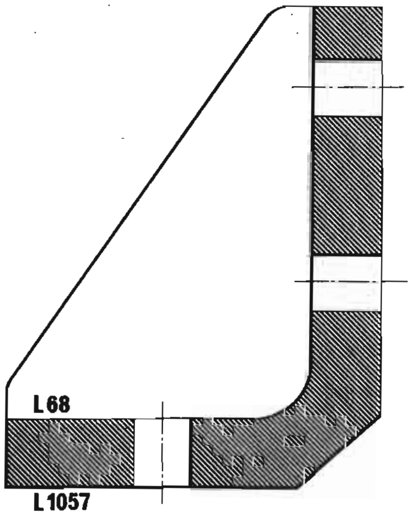


FIG. 4. 'PART' ANNOTATION

FIG. 5. N.C. INSPECTION MACHINE

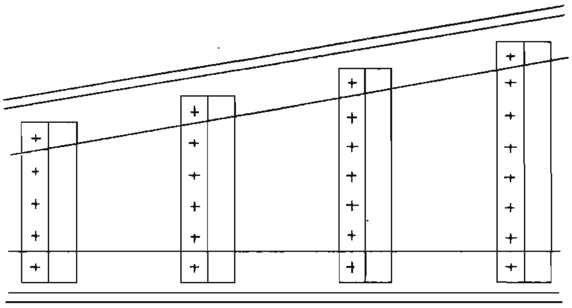


FIG. 6. REPEATED CALL

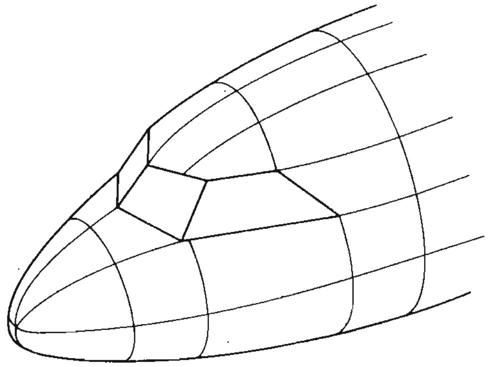


FIG. 7. NUMERICAL MASTER GEOMETRY

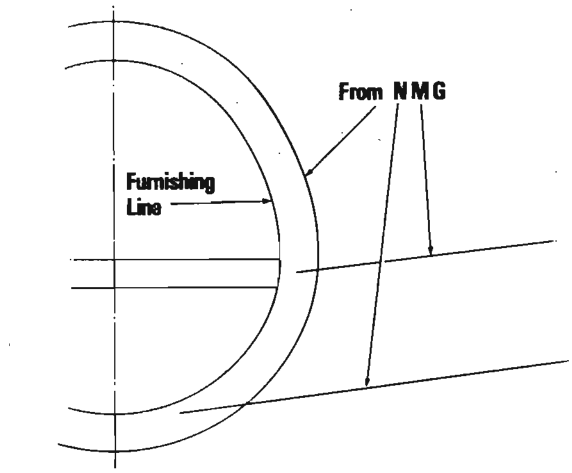


FIG. 8. FRAME BOUNDARIES

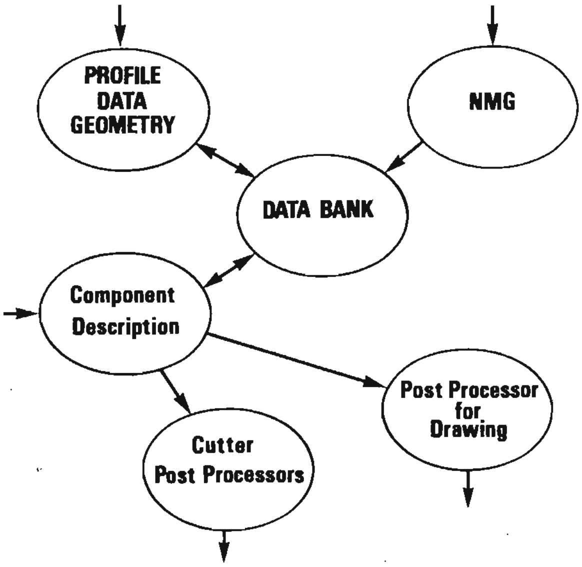
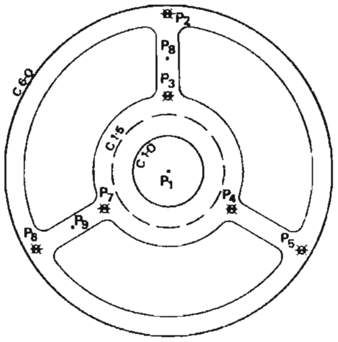


FIG. 9. COMPUTER SYSTEM

* Fillet Radii
* Composite curves
* Symbolic distances
* Repeat codes
* Macro facilities

FIG. 10. 'PROFILE DATA' ENHANCEMENTS

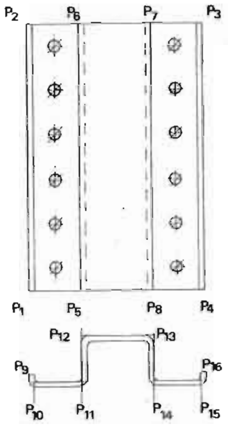


P_1 - P_9 Previously Defined Points

⊗ is a Standard Symbol Called CROA

```
ATP1;LD;FC1.5;LF;FC1.0;FC6.0;
LS(CROA);SEQ 2 7;FR.5;OR.25;LF;
MP8;P3;CCP1CP4;P5;CCP1AP2;P8;
MP8;P2;CCP1AP6;P7;CCP1CP3;P8;
MP9;P6;CCP1AP5;P4;CCP1CP7;P9
STOP
```

FIG.11A. DRAWING LANGUAGE



P_1 - P_{16} Previously Defined Points

⊗ is a Standard Symbol Called CROA

```
ATP1;P2;P3;P4;MP5;P6;MP7;P8;
OR.064;MP1;P2;MP3;P4;
LD;MP5;P6;MP7;P8;
FR.2;FL.264;MP9;SEQ 10 16;
OZ;MP9;SEQ 10 16;
LSA(CROA);NS6;OR.5;
MP1;P2;MP3;P4;STOP;
```

FIG.11B. DRAWING LANGUAGE

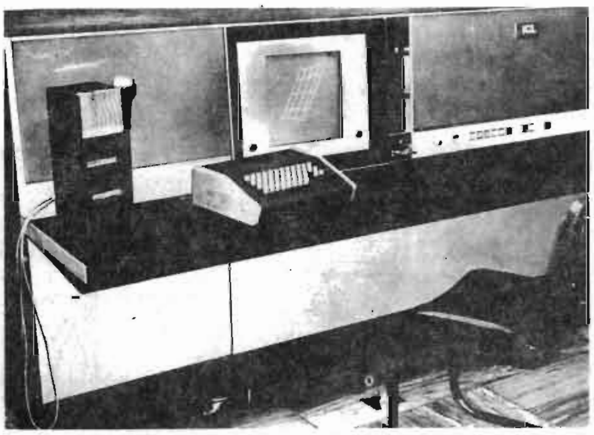


FIG.12 A. 1830 GENERAL VIEW

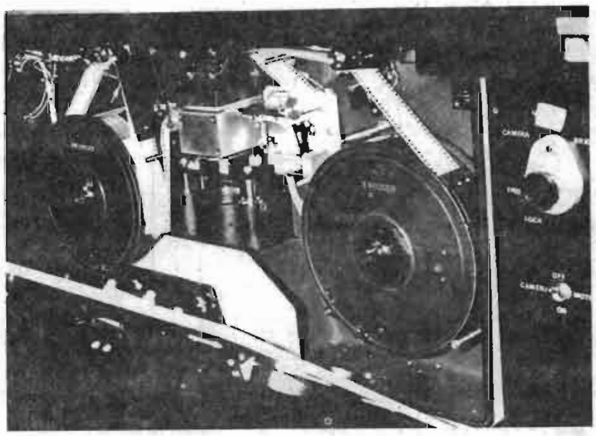


FIG. 12 B. 1830 MICROFILM RECORDER

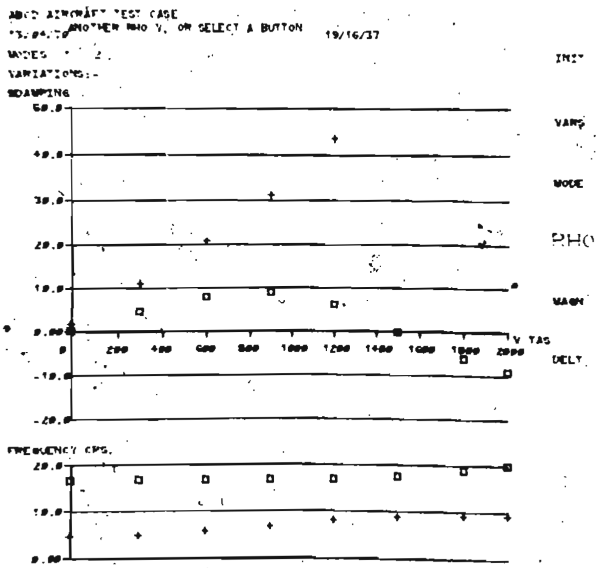


FIG.13. FLUTTER

FIG.14. COON'S PATCH

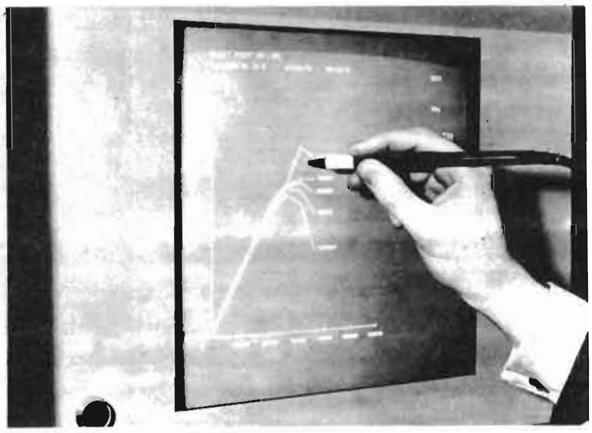
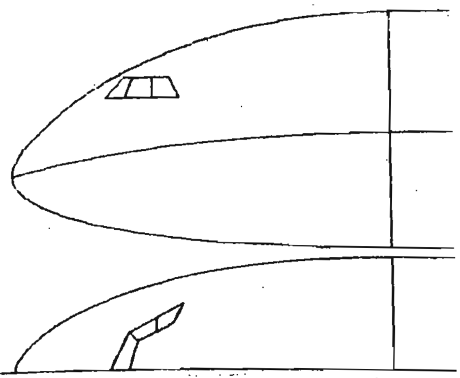
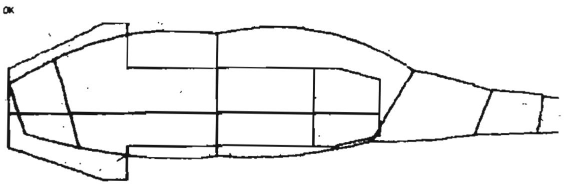


FIG.15. CURVE EDITING



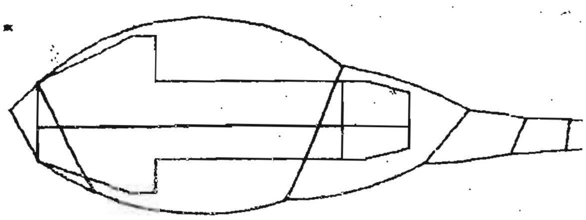
```
YM   .000000E0 XE   140.000  X1   100.000  Y1   .000000E0 Z1   80.0000
ZM   .000000E0 YE   20.0000  X2   120.000  Y2   .000000E0 Z2   100.000
WM   20.0000   ZE   90.0000  X3   130.000  Y3   30.0000   Z3   100.000
YP   400.000   I             X4   120.000  Y4   40.0000   Z4   80.0000
ZP   40.0000   I             X5   150.000  Y5   55.0000   Z5   80.0000
WP   120.000                 X6   150.000  Y6   40.0000   Z6   100.000
SF   2.00000                 X7   170.000  Y7   50.0000   Z7   100.000
                             X8   100.000  Y8   70.0000   Z8   80.0000
```

FIG. 16A. VISION ENVELOPE



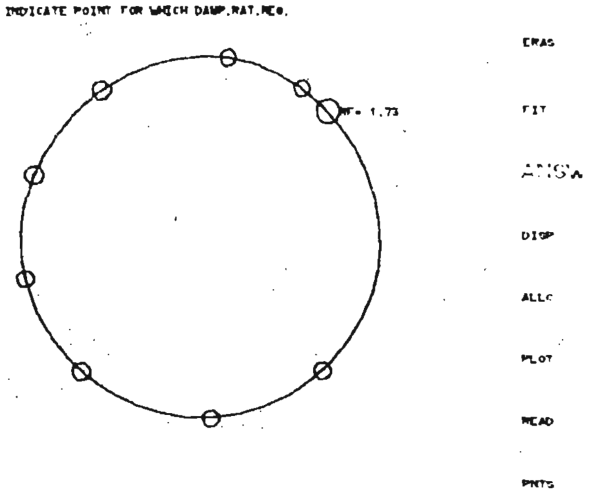
```
XM   .000000E0 XE   140.000  X1   100.000  Y1   .000000E0 Z1   80.0000
ZM   .000000E0 YE   20.0000  X2   120.000  Y2   .000000E0 Z2   100.000
WM   20.0000   ZE   90.0000  X3   170.000  Y3   30.0000   Z3   100.000
XP   400.000   I             X4   120.000  Y4   40.0000   Z4   80.0000
ZP   40.0000   I             X5   150.000  Y5   55.0000   Z5   80.0000
WP   120.000                 X6   150.000  Y6   40.0000   Z6   100.000
SF   2.00000                 X7   170.000  Y7   50.0000   Z7   100.000
                             X8   100.000  Y8   70.0000   Z8   80.0000
```

FIG.16B. VISION ENVELOPE



```
XM   .000000E0 XE   140.000  X1   100.000  Y1   .000000E0 Z1   80.0000
ZM   .000000E0 YE   30.0000  X2   120.000  Y2   .000000E0 Z2   100.000
WM   20.0000   ZE   95.0000  X3   170.000  Y3   30.0000   Z3   100.000
XP   400.000   I             X4   120.000  Y4   40.0000   Z4   80.0000
ZP   40.0000   I             X5   150.000  Y5   55.0000   Z5   80.0000
WP   120.000                 X6   150.000  Y6   40.0000   Z6   100.000
SF   2.00000                 X7   170.000  Y7   50.0000   Z7   100.000
                             X8   100.000  Y8   70.0000   Z8   80.0000
```

FIG.16C. VISION ENVELOPE



```
INDICATE POINT FOR WHICH DAMP.RAT.REQ.
```

FIG. 17. FREQUENCY RESPONSE CURVE FITTING