RATIONALISATION AND IMPROVEMENT OF A COMPANY'S ENGINEERING DESIGN PROCEDURES

by

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SUMMARY

There is a great deal of literature about the initial stages of innovative design. This is the process whereby a completely new product is conceived, invented and developed. In industry, however, the continuing success of a company is more often achieved by improving or developing existing designs to maintain their marketability. Unfortunately, this process of design by evolution is less well documented. This thesis reports the way in which this process was improved for the sponsoring company.

The improvements were achieved by implementing a new form of computer aided design (C.A.D.) system. The advent of this system enabled the company to both shorten the design and development time, and also to review the principles underlying the existing design procedures.

C.A.D. was a new venture for the company and care had to be taken to ensure that the new procedures were compatible with the existing design office environment. In particular, they had to be acceptable to the design office staff.

The C.A.D. system produced guides the designer from the draft specification to the first prototype layout. The computer presents the consequences of the designer's decisions clearly and fully, often by producing charts and sketches.

The C.A.D. system and the necessary peripheral facilities were implemented, monitored and maintained. The system structure was left sufficiently flexible for maintenance to be undertaken quickly and effectively. The problems encountered during implementation are well documented in this thesis.

Engineering design.
Computer aided design.
Project implementation.

To the ascent and clear sight.

ACKNOWLEDGEMENTS

I would like to acknowledge the guidance and support of both my university supervisors: Mr. G.A. Montgomerie and Mr. R.G. Taylor, and my industrial supervisors: Dr. C.J. Hooke, Mr. P.J. Cleife, and Mr. F.W. Baggett.

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GLOSSARY OF TERMS

Design

Design method:	The means of producing a new design to satisfy a specification using the available resources.
Design specification:	Set of criteria to be satisfied by the design.
Design procedures:	Specific routines for carrying out part or all of the design method.
Contract:	A venture undertaken by the company in order to produce a new model. This will normally consist of three phases: design, development and production. A feasibility study may precede the first phase.
Lead time:	The period of elapsed time or delay associated with a specific activity. In this thesis the lead time on the design and development phases is discussed.
Unit:	A hydraulic pump, motor or transmission (i.e. one specific machine).
Model:	A category comprising all units with the same specification and geometry.
Scheme layout:	A scale sketch showing the components of a unit in their assembled positions.
Design system:	A framework for carrying out design procedures. The system devised in this project comprised three main stages: a design feasibility stage (stage 1), a design stage (stage 2), and a performance analysis stage (stage 3).
C.A.D.S.:	Computer aided design system. The title given to the computer based design system devised in this project.
Design suite:	Collective term for the programmes constituting stage 2 of the three stage design system.
Design package:	A programme capable of being used as either an individual design aid or as part of the stage 2 design suite.

Module:	An interchangeable section of a programme with a specific function. The modular philosophy of programming results in programmes that are easy to maintain.
Administration:	Those parts of the design method concerned with the structuring, planning and ordering of the individual design procedures.

Hydraulics

Hydraulic pump:	A machine that converts mechanical power from a drive shaft into hydraulic fluid power.
Hydraulic motor:	A machine that converts hydraulic fluid power into mechanical power at the output shaft.
Hydrostatic transmission:	A machine which provides a continuously variable gear ratio between the drive and output shafts. It normally consists of a pump and motor coupled hydraulically.
Axial piston machine: Bent axis machine: Gear machine:	Three common varieties of pump, motor and transmission. The axial piston machine is the variety manufactured by the sponsoring company; the design of these is the subject of this thesis.

Computing

Mainframe computer:	A large computer (usually greater than 200K memory size). These normally serve a number of company departments.
Minicomputer:	A small computer (usually less than 150K memory size). These normally serve only one company department.
Computer system:	Collection term given to the computer hardware and the manufacturer's software. The latter provides facility for programme development, editing, time sharing etc.
Hardware:	The physical components constituting the computer.

Software:	Programmes devised by a programme writer for controlling the operation of the computer. These are normally stored on magnetic tape or disc, but may be listed in textual form on a line printer.
RSX 11D:	The basic software provided by Digital Equipment Corporation Ltd. for the minicomputer.
DATS 11:	Further software provided by the Institute of Sound and Vibration Research, University of Southampton to supplement that provided by D.E.C.
Computer language:	Code used for writing computer software.
Central processor:	The "brain" of the computer that performs the basic arithmetic operations and organises the operation of peripherals.
Peripheral:	Any computer driven device that can be coupled into the computer system e.g. plotter, line printer, V.D.U.
Disc:	A device for storing software or data not immediately required by the central processor. A disc consists of a number of parallel circular plates covered with a magnetic coating on to which the data is written.
Memory:	The part of the computer used for storing all of the data and software required by the central processor at any one time. The memory size is measured in terms of the amount of information that can be held. 1K of memory can accommodate 1024 integers.
On-line:	The adjective used to describe a peripheral that is coupled directly into the computer system.
Interactive:	The adjective used to describe the situation in which data exchanges between the user and the computer can be made very rapidly, thus allowing effective man-computer dialogues to take place.

Batch processing:	Process whereby the computer executes complete tasks sequentially. There is thus usually a delay between initiation of a task and the start of its execution. No communication can take place between the user and computer during the execution.
Data structure:	An ordered set of computer files used to house information required by the computer or its users. In the case of a minicomputer these files are normally stored on disc.
Visual display unit: (V.D.U.)	A device capable of accepting and presenting textual information. These are used for communicating with the computer.
Graphics terminal:	Similar to a V.D.U. but capable of handling also pictorial information.
Data logger:	A device for collecting and recording measurements from monitoring instruments during an experiment or test.

0. PREFACE

The project described in this thesis was commissioned by Commercial Hydraulics Ltd. and accomplished through the Interdisciplinary Higher Degrees (I.H.D.) scheme of the University of Aston. It was supervised by both representatives of the company, and members of university departments. The nature of the I.H.D. scheme enabled resources to be drawn from the faculties of applied psychology, computing and mechanical engineering as well as from the company. An outline of the project is given in fig 0.1 which shows why a multi-disciplinary approach was necessary.

The benefit for Commercial Hydraulics ensues from the work carried out during the project, not from this thesis which is, rather, a description and evaluation of the work. Figure 0.2 summarises the way in which this work is reported in the thesis.

Objectives

i) To review the design procedures of the sponsoring company.

ii) To devise means whereby the design procedures could be undertaken more effectively.

iii) To implement the devised methods in the design office environment.

iv) To evaluate the outcome for the company and its staff, and the possible implications for other such design situations.

Method - by pursuing the following steps:-

i) Personal involvement in the company's design procedures.

ii) Literature review and appraisal of different design philosophies and aids.

iii) Selection of appropriate alternative for this company.

iv) Development of C.A.D. framework and design software.

v) Release of system and use in design office.

vi) Observation and adaption of the system, and establishment of software maintenance procedures.

vii) Evaluation by analysis of data collected during and after release.

Outcome

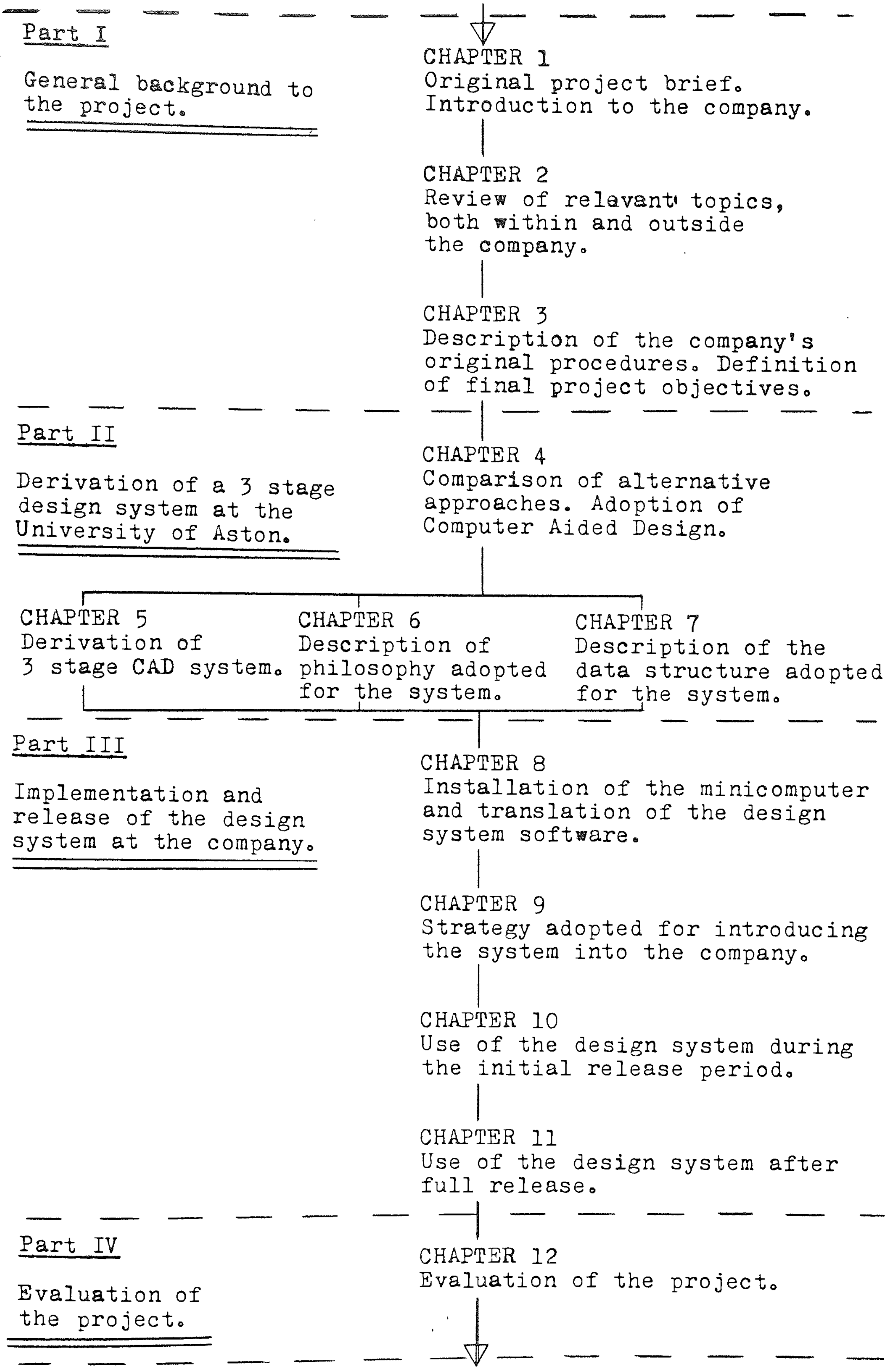
i) A more effective and systematic design method for hydraulic pumps resulting in a reduction in the design and development lead time. This method is based on an interactive C.A.D. system which incorporates:-

  a) Ways of coupling a design system and an information retrieval system so as to reduce time spent searching for data.

  b) Development of more effective ways of using computers in the fields of data presentation and interaction.

ii) An evaluation of the implemented design system, and a comprehensive case study in incremental design.

FIG 0.1 PROJECT SUMMARY



Part I

General background to the project.

CHAPTER 1
Original project brief.
Introduction to the company.

CHAPTER 2
Review of relevant topics, both within and outside the company.

CHAPTER 3
Description of the company's original procedures. Definition of final project objectives.

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CHAPTER 12
Evaluation of the project.

FIG 0.2 Plan of the thesis

PART I

1.0. INTRODUCTION

1.1. Description of the Sponsoring Company and its Function

In September, 1975, an appraisal of the design method of Commercial Hydraulics Limited, (Glos.), was begun. The object was to rationalise and improve the company's machine design procedures. It was hoped that this would result in a more certain design method involving fewer post-prototype design modifications.

The Gloucester division is one of a number spread throughout Europe. Commercial Hydraulics is itself a subsidiary of the American holding company Commercial Shearing Inc. This hierarchy is summarised in figure 1.1.

The sponsoring division has two distinct functions; the first is to act as the European Engineering Centre of the group; the second is an activity peculiar to this division and largely independent of the group, and concerns the production of special purpose-built machines for customers in Britain.

As shown in figure 1.1, the work done at the division is in the field of hydraulics, the main product line being hydraulic pumps and motors. These are combined to form purpose built transmissions for British customers.

The size of the division at the start of the project was about 50 employees, of which 12 worked on research, design and development in the design office. At the time the division was expanding rapidly and by January 1978 the number of staff had increased to over 100; fourteen engineers worked on design and development and a further seven worked

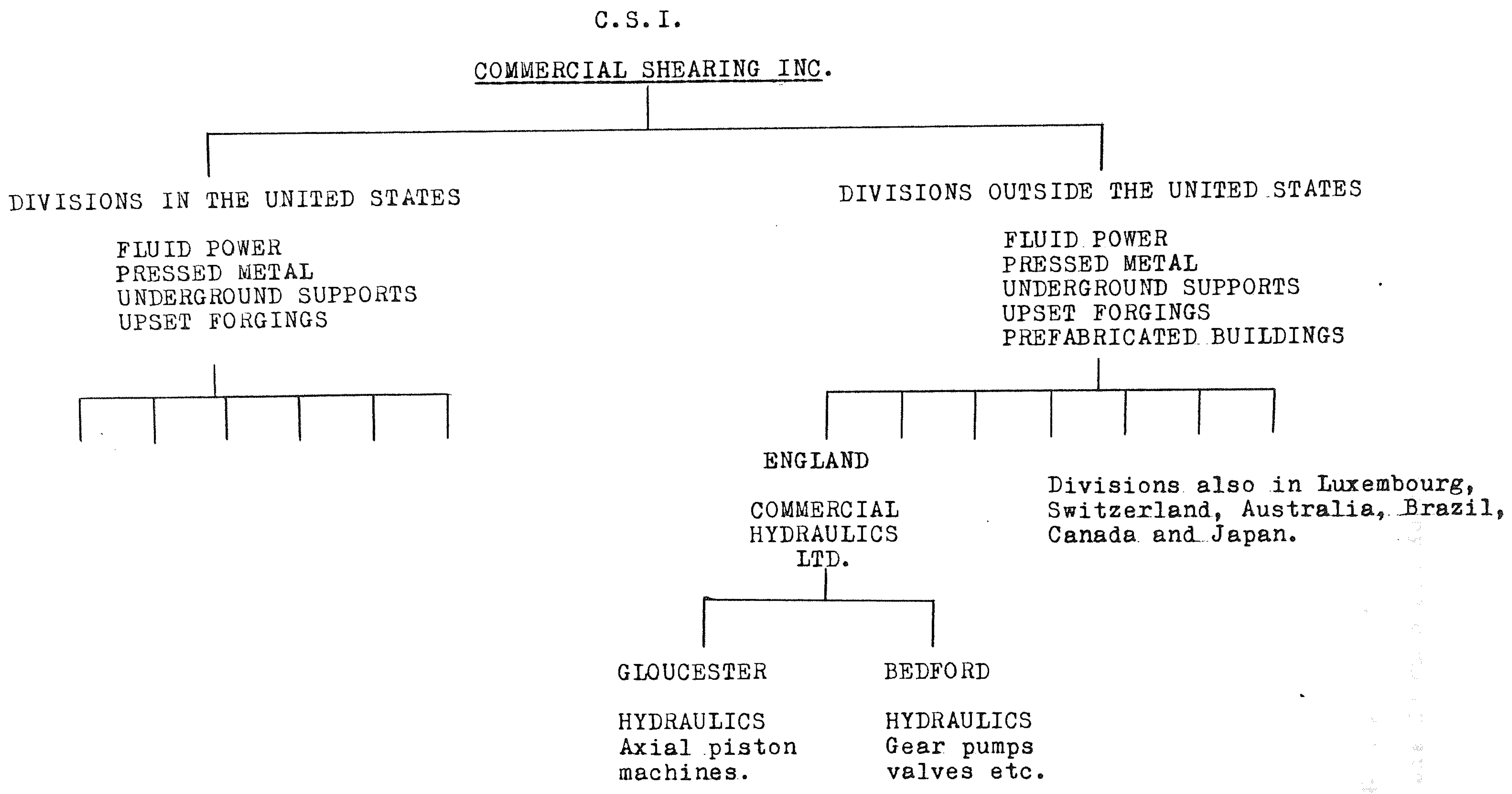


FIG. 1.1 Company structure of Commercial Shearing Inc.

full-time on research.

The pumps and motors produced by the company are axial piston machines. These fall into the category of high pressure (typically around 350 bar), medium speed (around 3000 rev/min) machines and are used mainly in servo-control systems and hydrostatic transmissions. The general position of this kind of machine in the overall hydraulic pump and motor market is shown in figure 1.2, although the boundaries between the different types are fairly flexible.

The general layout of an axial piston pump is shown in figures 1.3 and 1.4. A number of pistons (1) reciprocate inside a rotating cylinder block (2) and cause oil to be pumped from the low pressure port to the high pressure port of the pump through a portplate (3), fixed relative to the case. The drive to the cylinder block is transmitted through a spline on the drive shaft (4). The flow capacity of a unit can be changed either by altering the rotational speed, or by altering the angle of the swivelling swash plate (5) to adjust the stroke of the unit. Although this kind of machine is not new, (early models date from 1907[1]), as with the petrol engine, development effort is still very intense. With the pumps, for instance, demand continues for models with different speed-pressure-flow capacity combinations. These are the main performance criteria. There are many others, their nature depending on the intended environment of the pump.

Over the years, a great deal of experience of designing these machines has been amassed by manufacturers. Also new technology is continually being fed into the industry

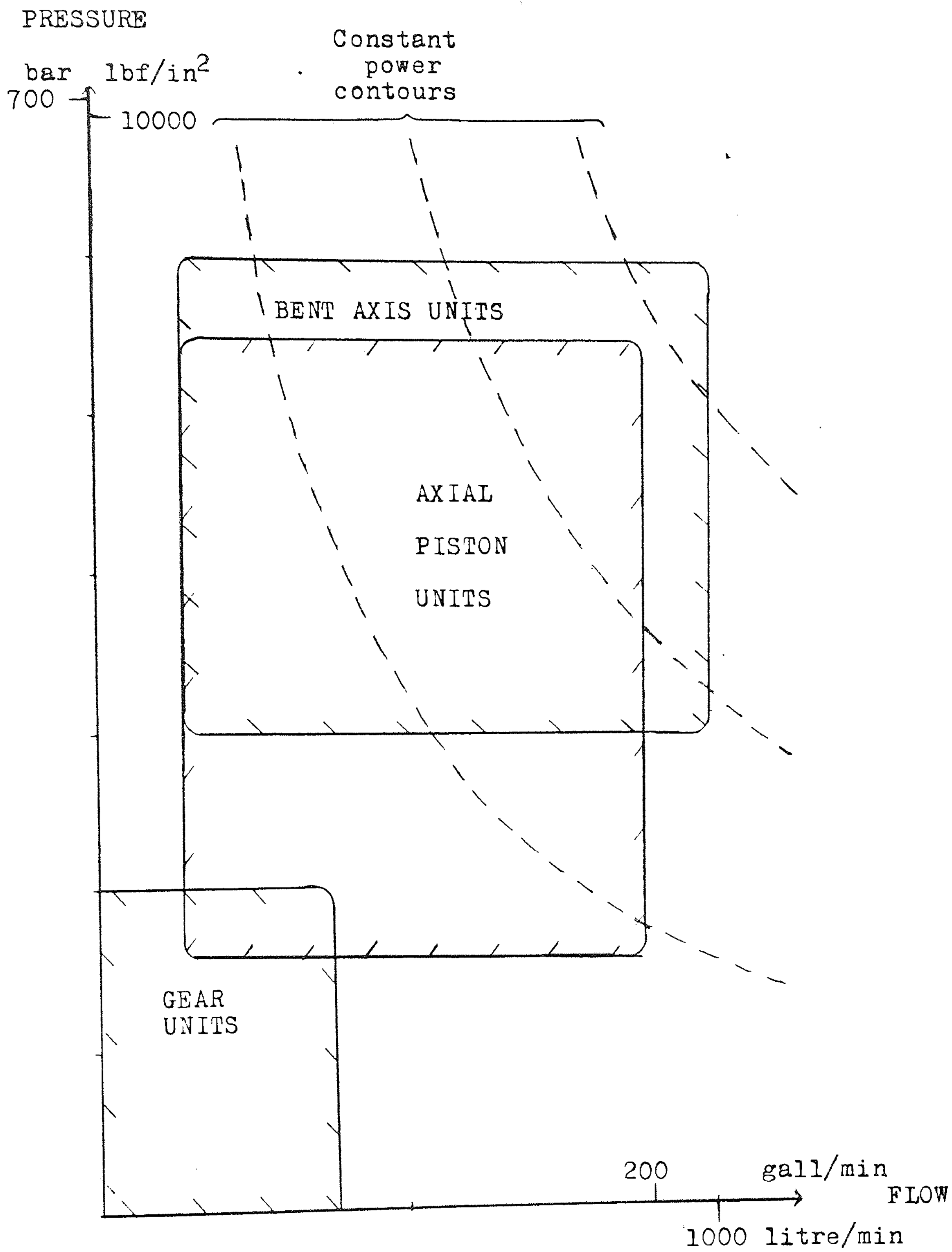


FIG. 1.2 Position of the Axial Piston Pump in the hydraulic pump market

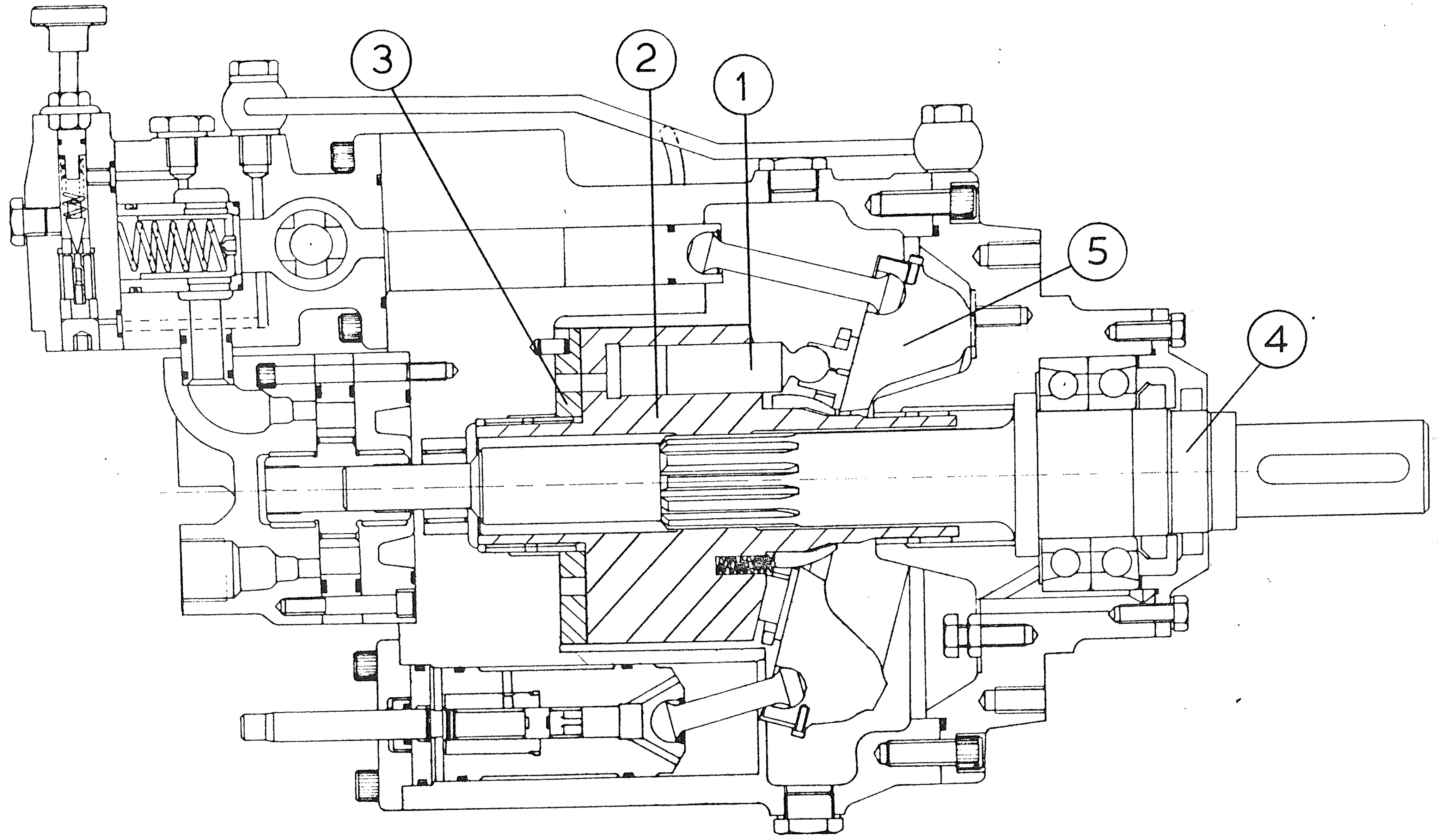


FIG. 1.3 General layout of an Axial Piston Pump

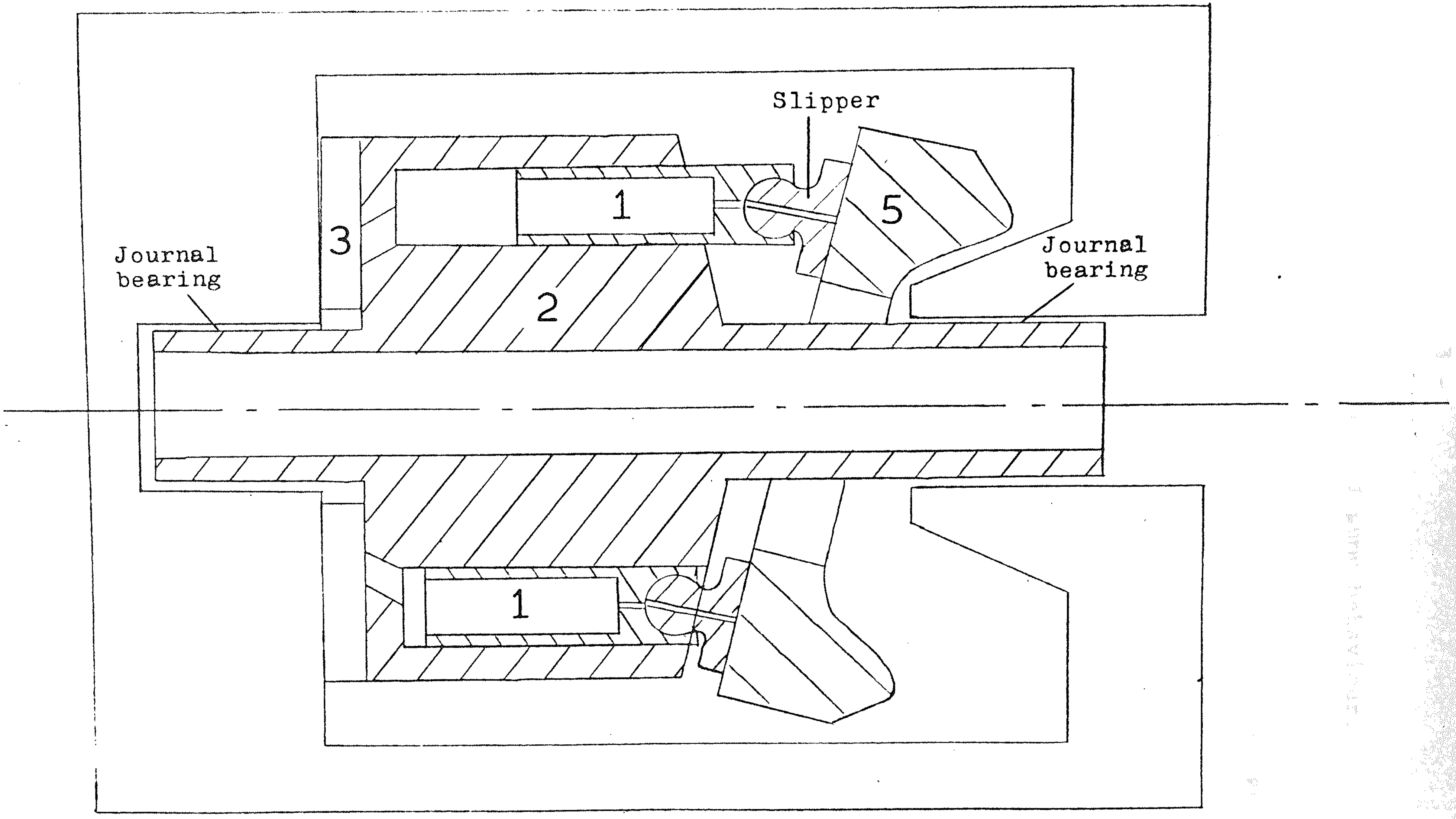


FIG. 1.4 Simplified scheme of an Axial Piston Pump

to enable a better understanding of pump behaviour.

1.2. Original Aims of the Project

A great deal of information pertinent to the design of axial piston pumps existed at the start of the project. In the case of the sponsoring company, some of this was stored formally as reports etc., and some was stored informally as the experience and knowledge of employees. Further information remained to be captured from outside the company. This situation is summarised in figure 1.5 which shows the different forms of information feeding into the design process.

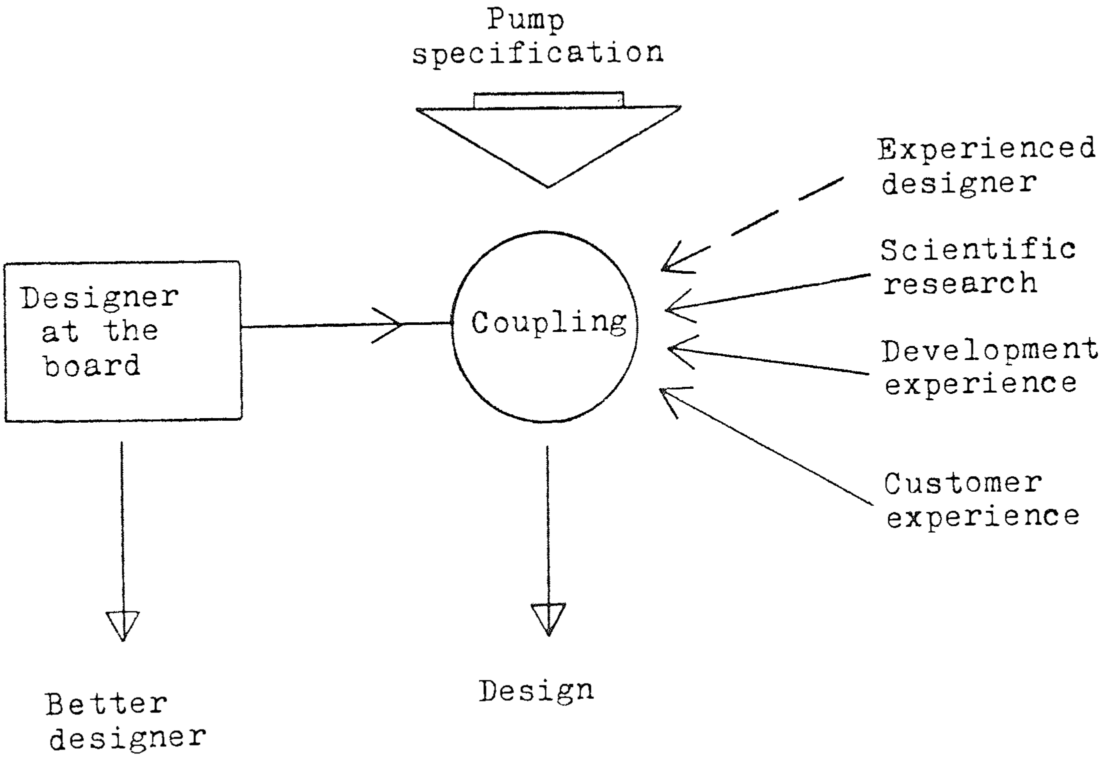


FIG. 1.5 Inputs to the process of design

Design is naturally a very important part of the company's work. It is both the first phase in the production of special transmissions, and an important aspect of the engineering work done for other members of the group. Common to these activities is the task of designing or re-designing axial piston machines. If this design task could be made more certain, then savings would ensue by virtue of a shorter development time, lower cost, and greater reliability of the units. A shorter design time would also enable tenders to be submitted to prospective customers more rapidly, and hence would increase the company's chance of capturing orders. This argument led to the following original aims of the project:

(i) To make alterations to the design method so that a unit designed and developed would be closer to the final design first time and would, therefore, require a shorter design-and-development lead time.

(ii) If possible, to reduce the time taken to design a new unit as far as the prototype production stage.

Before these aims could be achieved it would be necessary to investigate the design process depicted in figure 1.5 to uncover areas where improvements could be made. Furthermore, in order to evaluate any attempts to achieve these aims, a comparison of the design process before and after alteration would be necessary. The original process could be examined at the start of the project, but in order to obtain post-alteration data, time would have to be allowed for implementation and monitoring of any new design method.

2.0. DESIGN CONSIDERATIONS

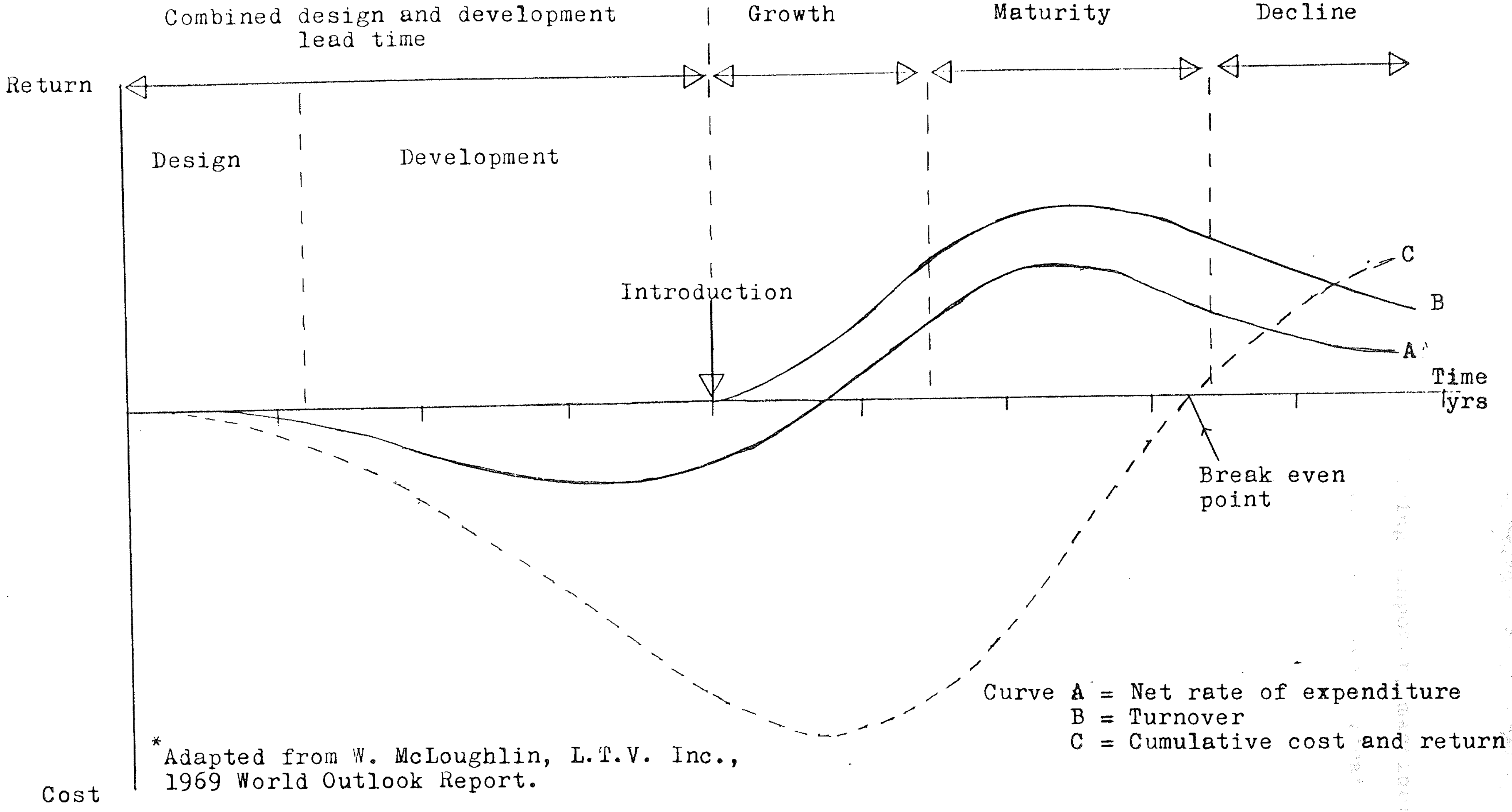
Before the final project objectives could be decided, it was necessary to review some of the subject areas relevant to design. These areas are described in this chapter. First a general description of design processes is given (section 2.1); this is then related to the circumstances of the sponsoring company, section 2.2. Finally a section on human factors explains the importance of considering the user's requirements in a project of this type, (section 2.3).

2.1. Design processes in general

2.1.1. Design criteria and resources

Design consists in satisfying objectives subject to certain constraints or criteria. The basic criteria are defined in a specification or brief which should contain information sufficient to a solution attempt. The criteria fall into a number of categories: technical, economic, ergonomic, aesthetic. Of these categories, probably the technical is that foremost in the designer's mind during initial design, although the cost and ease of maintenance of a product, for example, are just as important as the technical adequacy. Beakley and Chilton [2] demonstrate this with several case studies. In many cases, the complexity of the technical considerations monopolises the designer's concentration.

The fundamental resources necessary for carrying out any task are time and money. In industry the success of a venture often depends on the time taken to develop a new product or prepare a tender for a prospective customer; this is shown in figure 2.1. As time always costs money, any time



*Adapted from W. McLoughlin, L.T.V. Inc., 1969 World Outlook Report.

FIG. 2.1 Course of a typical contract

saving is clearly welcome.

Money is also necessary for buying manpower, machinery, space and materials. These four quantities have a great bearing on a company's design capability, especially when it is desirable to manufacture a product in house with the available machinery, materials and expertise. In these circumstances a slightly inferior design may be traded off against the benefit of familiar production techniques.

The basic resources described above are usually implicit in the design brief. More relevant when devising new design methods are the specific resources which a designer may use during his work: experience, engineering knowledge, experiment and technology.

Experience will have been gained by the designer and his collegues on previous contracts, both successes and failures. This experience is useful provided that it does not stifle the other resources.

Engineering knowledge comprises the physical and natural laws that fundamentally constrain a design. The designer obviously has no control over these, but a good working knowledge is essential in engineering design.

Experiment can yield a wealth of information in circumstances where the corresponding theory is intractable or necessitates a large number of approximations. Gregory [3] criticises the modern trend towards rejecting data giving situations in favour of mathematical models.

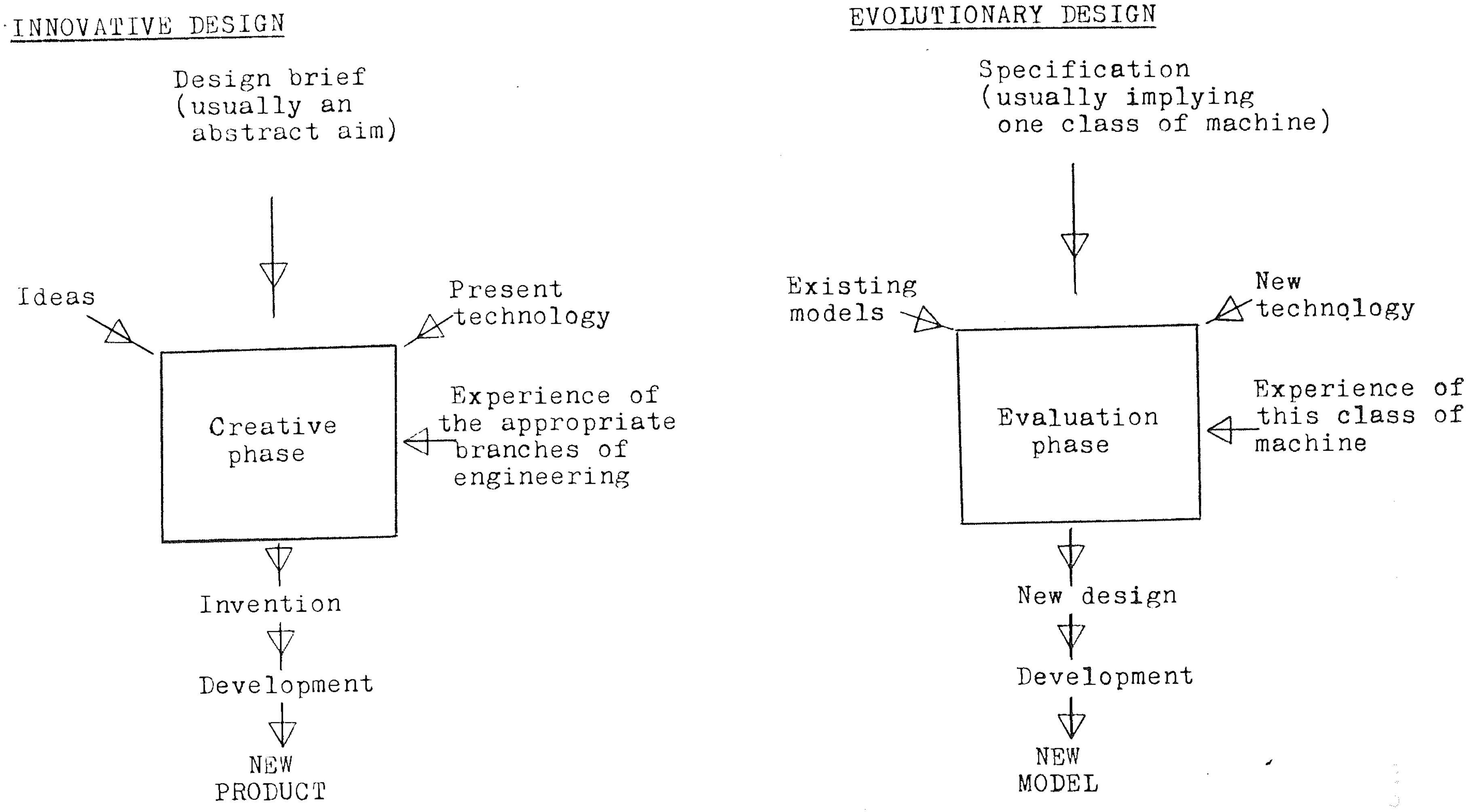
Technology concerns the availability of ever increasing amounts of information and the discovery or invention of new methods and materials. It is often by applying new technology that improved designs are made possible. However, there are often problems in transferring technology from the universities or research establishments into industry where it can be applied.

One major problem common to all these areas is that of storing the information sensibly so that a designer might readily call on it. This, in itself, is the subject of a great deal of research.

2.1.2. Evolutionary and Innovative design procedures.

Many texts agree that different types of design work can be distinguished according to the nature of mental activity involved. Furman [4] distinguishes between repetitive, evolutionary and innovative. Asimov [5] simply distinguishes between innovative and evolutionary design; these classes are depicted in figure 2.2.

Design by evolution is concerned with modifying or improving an existing design concept to produce a new member of a particular design family to a different specification. The need for a new model might, for instance, arise from a customer's requirements or a desire to enter a new market. This process is exemplified by the motor industry where the design of a new engine is a rare occurrence and more often the bore, stroke or some other facet of the design will be altered to satisfy a new specification. Thus, evolutionary design can play a large part in the success or failure of industries, but suprisingly it attracts little attention in design texts. This is probably because the processes are often very specific to one particular company and generalisations are difficult to make.



INNOVATIVE DESIGN

EVOLUTIONARY DESIGN

FIG. 2.2 Comparison of innovative and evolutionary design processes

2.1.3. Design phases

Most engineering design, whether innovative or evolutionary in nature, passes through three phases. These are:-

(i) A feasibility study.

(ii) A preliminary design phase

(iii) A detailed design phase

These phases are clearly defined by Asimov [6]. Ideally a design would pass through each of these phases just once, but in practice it is often necessary to feed back to an earlier phase to crystallise or improve ideas. As these phases are being pursued, the main activities of the designer are analysis, synthesis and evaluation. Mesarovic [7] suggests the model of the design process shown in figure 2.3.

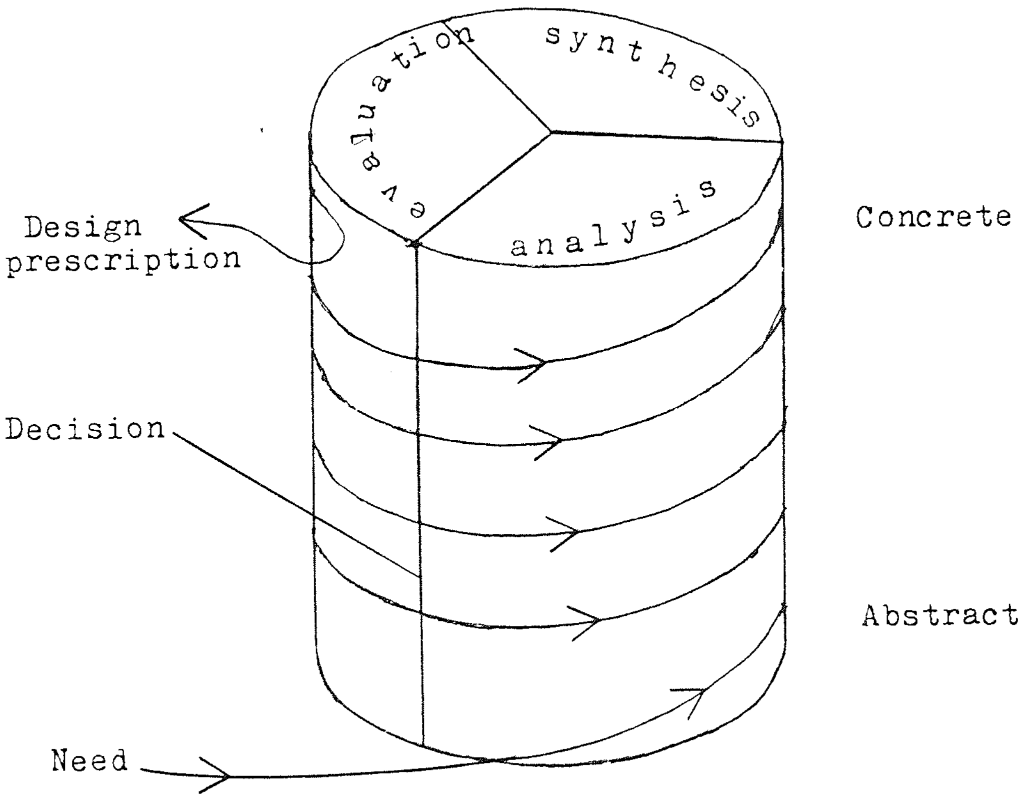


FIG. 2.3 Mesarovic's model of the design process

The designer here repeatedly circulates the cylinder gaining greater and greater confidence in his concepts until they are sufficiently concrete to form a design prescription. Of course, not all designs will follow a steady, upward trend, indeed, poor designs should never reach the top of the cylinder. The model suggests that a systematic design method might be achieved by controlling the progress of the line on the cylinder, perhaps to avoid sudden drops.

At the start of the feasibility study, the design task is specified, probably in a design brief; this is in itself a crucial step, as overspecification can cause as much trouble as underspecification by imposing unnecessary constraints on the design. The designer then identifies the factors limiting his scope and produces ideas within these constraints in order to obtain a number of feasible designs.

In the preliminary design phase, the feasible designs are developed and analysed further. The benefits and shortcomings of alternatives are compared, and if not considered hitherto fundamental levels of practicability (such as the benefits of using standard parts and processes) will be considered. At the end of this phase, one or two concrete schemes are carried forward.

The detailed design phase follows and here the exact dimensions, tolerances and materials are decided. If possible, performance analyses are carried out and estimates made of reliability. Essentially this provides a last opportunity to modify the design before draughting of production drawings and prototype production.

2.1.4. Design problems

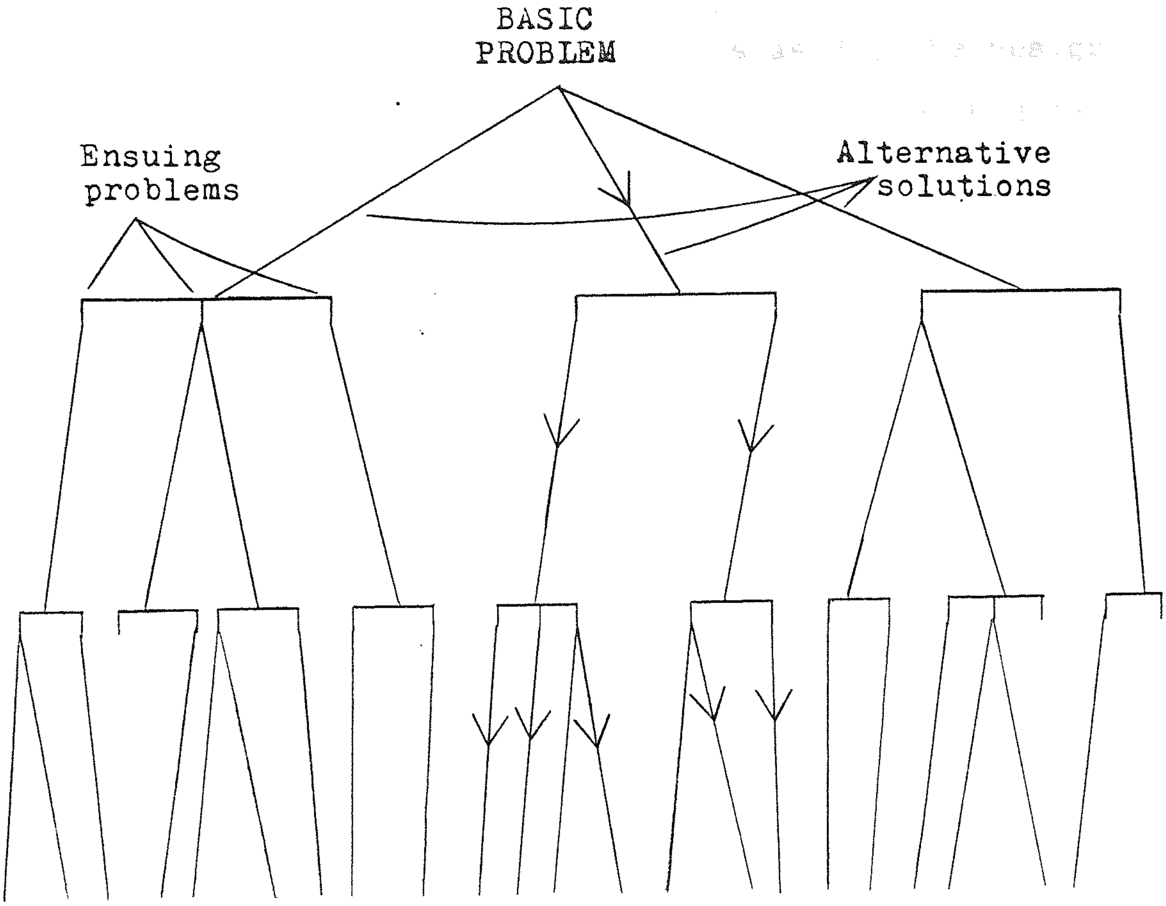
Probably the most difficult task of the design process is to determine what the real design objectives are and to set these down as a design brief or specification. Cain [8] suggests a number of requirement categories for the brief, but in most cases the brief is fairly open-ended; for instance to increase the power rating of a motor, or reduce the noise level of some machinery. In these cases, it is only after the first analysis phase that the true specification emerges.

The remaining problems can be split into three broad categories: satisfaction, optimisation and standardisation, these being the ones implied in the design aim, "to find the best solution using the available resources". These problems arise in all phases of the design process. Satisfaction concerns the achieving of a basic aim, for instance to attain a specified power. Optimisation ensures that the method is the best in some respect, and standardisation ensures that the solution ties in as closely as possible with the company standards and philosophy.

As Gregory [9] points out, decision making plays a very large part in all these activities. These decisions can never be made with certainty of the outcome. Decisions taken early in the process can set a design off in completely different directions and the full consequences may not become apparent until much later. Even then, unless the chosen design proves inadequate, other possible solutions may not be investigated. The design tree (Marples [10]) shows this situation clearly.

In figure 2.4, at the top of the tree is the basic problem. As we descend the tree, the different possible solutions and their consequences are expounded. Even for a simple engineering component, the tree will have many branches.

By using the available resources, the aim is to reduce the indecision so that a logical solution can be pursued.



(The arrows show one possible solution)

FIG. 2.4 Marples' design tree

In addition to the resources mentioned earlier in this chapter, a number of design aids can be very useful in this task. However, inevitably a compromise must be made between uncertainty and resource expenditure.

2.2. Company constraints

In this section we consider the design process more specifically in relation to the sponsoring company. This leads to a better definition of the project aims.

2.2.1. Solution approach

The sponsoring company produces mainly axial piston machines. Design work on these units is confined to the production of new models and the improvement of existing ones. Although new ideas are often fed into designs, the need to generate ideas is not as great as is necessary at the start of innovative design processes. This aside, the design process of the company is similar to that described in section 2.1. During the process there is a need to assimilate information from a variety of sources, to be able to analyse and evaluate this, and to make decisions accordingly. (A full description of the company's original design method is given in chapter 3).

In the company's experience there had been no shortage of ideas, but these were not processed formally and were often lost. Nor was there any shortage of information; development experience, company reports, applied research and engineering knowledge were all available, but this information was not stored or organised effectively. In sponsoring the project, the company hoped for an improvement in these aspects within the timescale of the project.

In order to achieve this improvement, the horizons of the project were limited to three basic approaches:-

(i) To decide on the best procedural form for the design; that is the best way in which the various inputs to design (experience, research, experiment etc.) might be coupled to produce that design, and the benefits this might have for the designer.

(ii) To determine the nature of a systematic pump design and produce the flow chart or procedures that would control this design activity.

(iii) To decide how any design procedures might best be adapted to the ergonomic needs of the user.

This narrowing of the project scope is shown schematically in figure 2.5.

All three approaches listed above might be adopted in parallel for the greatest improvement to the design method. However, in order to make rapid progress on the project despite the limited resource of one man, I decided to adopt primarily approach '(ii)' and to draw in aspects from '(i)' and '(iii)' as and when necessary.

At the same time it became necessary to limit the project in another respect. Although the design of pump running gear (figure 1.4) was effectively an evolutionary design task, the design of casing for these units was much more innovative, depending greatly on the duty of the pump or transmission. This latter task could not be accommodated by the approach adopted and, therefore, casing design had to be omitted from the project.

2.2.2. Aid category adopted

There are a number of categories of design aid which might be used to help a designer in various activities of the design process. These range from mental aids to analytical tools and from aids to creativity to basic memory aids. Some of these were reviewed early in the project (see appendix A) to discover which might be of most use. These aids can be divided into three broad categories; mental aids, analytical aids and data generators. The mental aids, such as brainstorming and synectics are intended to help the designer's conceptual skills. Analytical

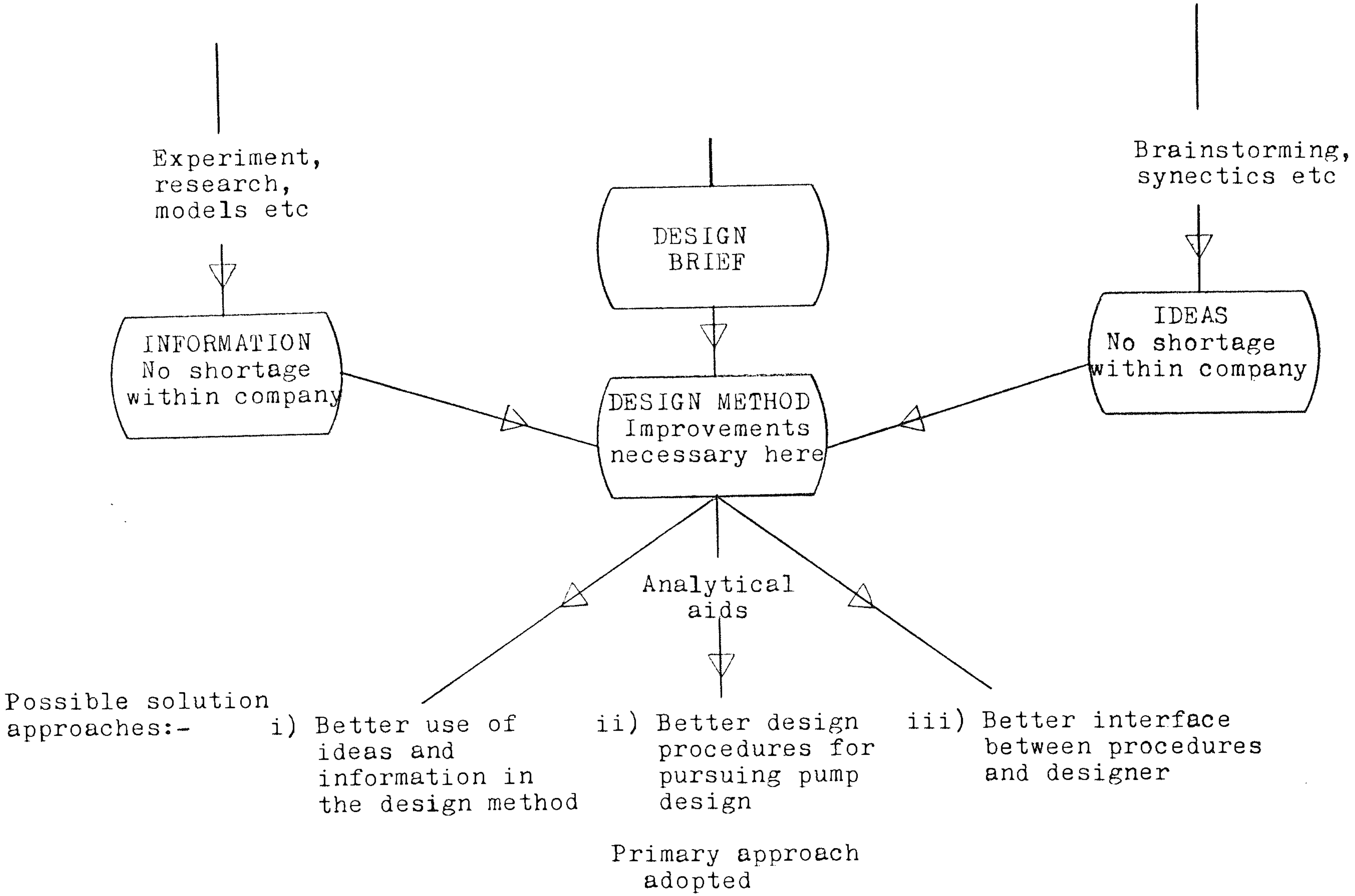


FIG. 2.5 The Design Process related to the sponsoring company

aids enable the designer to advance in specific design procedures; they include charts and manuals. The data generators include the use of model testing and experiment. Of these, the analytical aids are most suitable for use as a basis for systematic design procedures. This is shown in figure 2.5.

The class of aid can be further divided into two sets which we here define as non-computerised and computerised. The non-computerised set comprises charts, tables and manuals and the use of calculators to evaluate engineering equations or transpose values from one chart to another. This set enables convenient storage and evaluation of information. Furthermore, if the charts and manuals are well designed, they can also aid decision making by presenting results clearly to the designer.

The computerised set is an extension of the non-computerised set and covers a range from programmable hand calculators to large computers. These aids enable programming of the method and order in which non-computerised aids are used, the charts, tables and manuals usually having been converted to a form suitable for storage in the computer.

This is all that will be said of design aids for the moment. The development of a new design method using these aids will be described in detail in Chapter 4.

2.3. Human perspective

Figure 2.6 shows the task of improving design procedures from the job design point of view. It is essential to consider this aspect if new design methods are to be implemented successfully. The area within the dashed lines represents the various stages of job design. Outside this

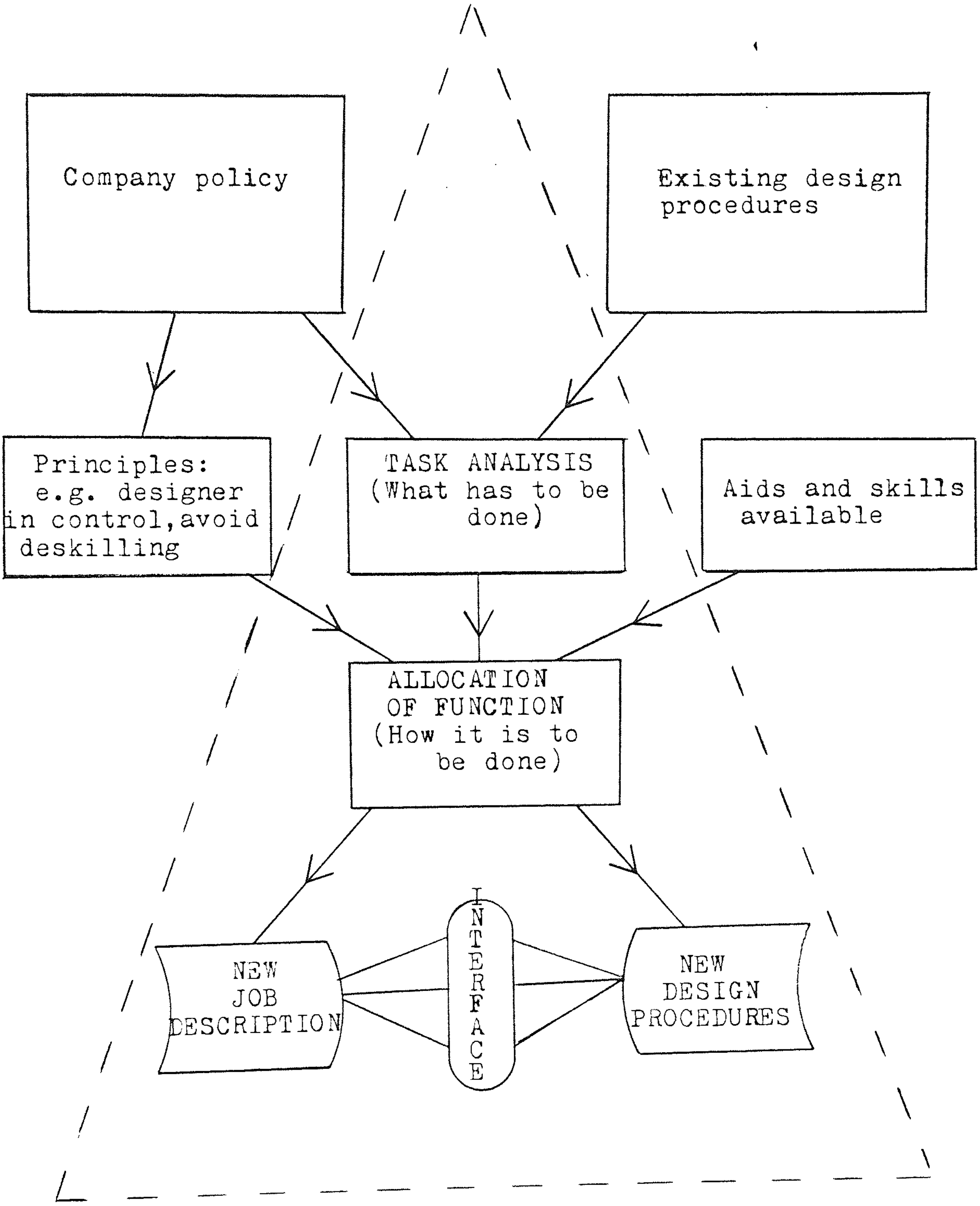


FIG. 2.6 Factors affecting job design

area are shown the external factors which determine the job; a few of these were defined in section 2.2; the remainder are defined in chapter 3.

In this section the general requirements of system users are described. This information will be useful both in establishing the final objectives of the project, and in devising new design procedures.

2.3.1. Motivation and job satisfaction

Motivation and job satisfaction are often coupled in discussions about work, however, the two are quite distinct. For example one employee might be quite satisfied with his job but uninterested in progressing his career, another might be dissatisfied with his lot but motivated to improve it. In most cases some balance between job satisfaction and motivation is desirable for the employee or employer. If the job is well designed the balance can prove desirable to both simultaneously.

Ross [11] suggests that the significant forces that motivate a man are the pursuit of esteem, security, knowledge and happiness. These may be categorised into three areas: personal factors, task factors, and organisational factors. Thus if we take 'security' and relate it to the three categories; in the organisational sense a designer might be worried about the policies or success of his company; in the task sense he might doubt the worth of his job; the personal aspect might be concerned with financial or family matters.

This method of classifying the factors in two dimensions is particularly useful when trying to increase job satisfaction in workers. In table 2.1 the factors that Herzberg[12] suggests are pertinent to motivation are classified in this way.

Using this table it is easy to spot the factors that can be altered by re-defining the job or reviewing company policy. Herzberg found that the most important factors were achievement, recognition, work itself, responsibility and advancement. Thus with reference to the table we would expect that much could be achieved by careful design of the job.

The survey carried out by Herzberg studied a sample consisting of engineers and accountants. The results from the two groups were similar, but it is noteworthy that the major difference was the pronounced interests, of engineers in responsibility and accountants in advancement.

The most important factor of those studied was achievement. This probably arises from the worker's desire to spend his time usefully. In this respect it is not sufficient for him to achieve something unless he recognises the fact himself.

Returning to figure 2.6, the above factors should be considered at the 'allocation of function' stage, before any new design method is formulated.

2.3.2. Psychological Factors

In considering psychological factors we are trying to avoid four mental states; fatigue, boredom, confusion and frustration. With reference to figure 2.7 we would like to design a job to be centrally placed within the square.

	ESTEEM	SECURITY	KNOWLEDGE	HAPPINESS
PERSONAL	Recognition	Inter-personal relationships		Personal life Salary
TASK	Status Responsibility	Job security	Advancement Possibility of growth	Achievement Work itself
ORGANISATIONAL		Company policy & administration		Working conditions

TABLE 2.1 Factors affecting Motivation

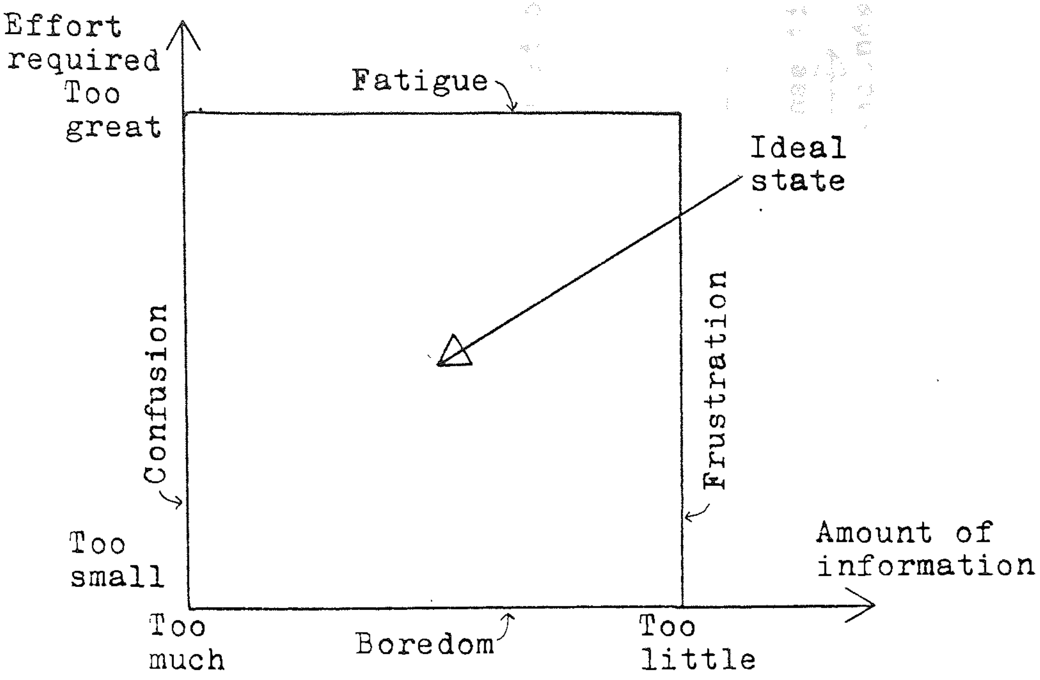
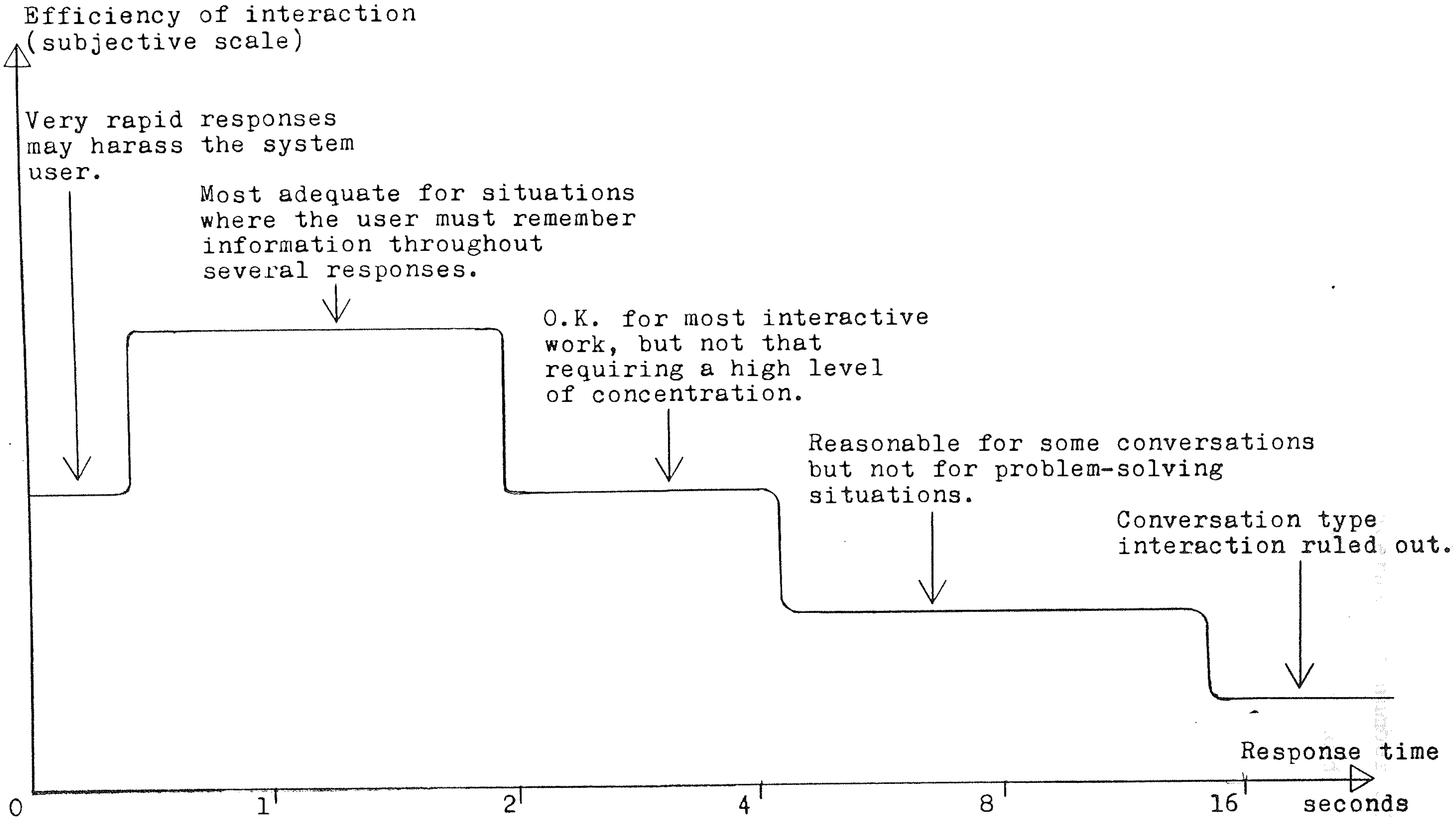


FIG. 2.7 Mental states to be avoided

To do this we need to know about response times, short term and long term memories, and channel capacities of humans. These are very general concepts and it is as well to remember that all individuals are different and there are serious dangers in catering only for the average man. Nevertheless, these concepts are still valuable in job design; they are considered in detail by Martin[13].

Response time is most important with computerised aids. With non-computerised aids, eg. the chart-manual-calculator set, the designer may progress at his own pace unhurried. However with a computerised system care must be taken to ensure that the designer is not hurried or made to wait as this will lead to a reduction in his level of concentration. Figure 2.8 shows this more clearly.



* Adapted from Martin[13]

FIG. 2.8 The effect of response time on the efficiency of interaction

Memory and channel capacity concerns the number of items of information which a designer can absorb and retain. A figure of seven has been experimentally found for these [14]. However, this should be interpreted carefully. It would be unreasonable to expect a designer to work with seven design charts simultaneously, but more reasonable to present him with an option list of seven alternatives in a computerised system.

These are just two examples which demonstrate again the importance of considering the user's requirements when planning to alter his job. All of these aspects will be considered when the new design method is developed in Part II of this thesis.

3.0. DEFINITION OF COMPANY'S FINAL BRIEF

In the last chapter, some of the factors affecting the solution approach were expounded. This led to a narrowing of the project scope and a decision to concentrate on improving the company's pump design procedures. In the second section of this chapter (section 3.2) the final objectives agreed by the project committee are described. Before this, in section 3.1, a more detailed description of the company's original design procedures is given. The last section of this chapter (section 3.3) introduces the final solution approach adopted for the project.

3.1. Description of the company's original design procedures

The design method used within the company in 1975 relied heavily on a designer's ability to recognise the criteria restricting and affecting the design. Unfortunately this meant that his memory was relied on as much as his experience and judgement, especially when drawing on information from past designs or trying to satisfy several criteria simultaneously.

To alleviate this situation and to make designers less dependent on the supervision of an experienced engineer a design manual had been produced summarising the basic procedures.

The way in which design work on each new contract was organised was as follows.

A senior engineer was allocated responsibility for the contract, but much of the preliminary design work was done by one or two less senior designers. These designers would endeavour to establish the viability of the contract by pursuing design alternatives at the drawing board. Feasible designs would be pursued as far as a draft scheme layout at which point the senior engineer would select a scheme to be checked and passed on to the detailed drawing phase. The design procedures used by the designers consisted of two operations performed alternately as shown in figure 3.1.

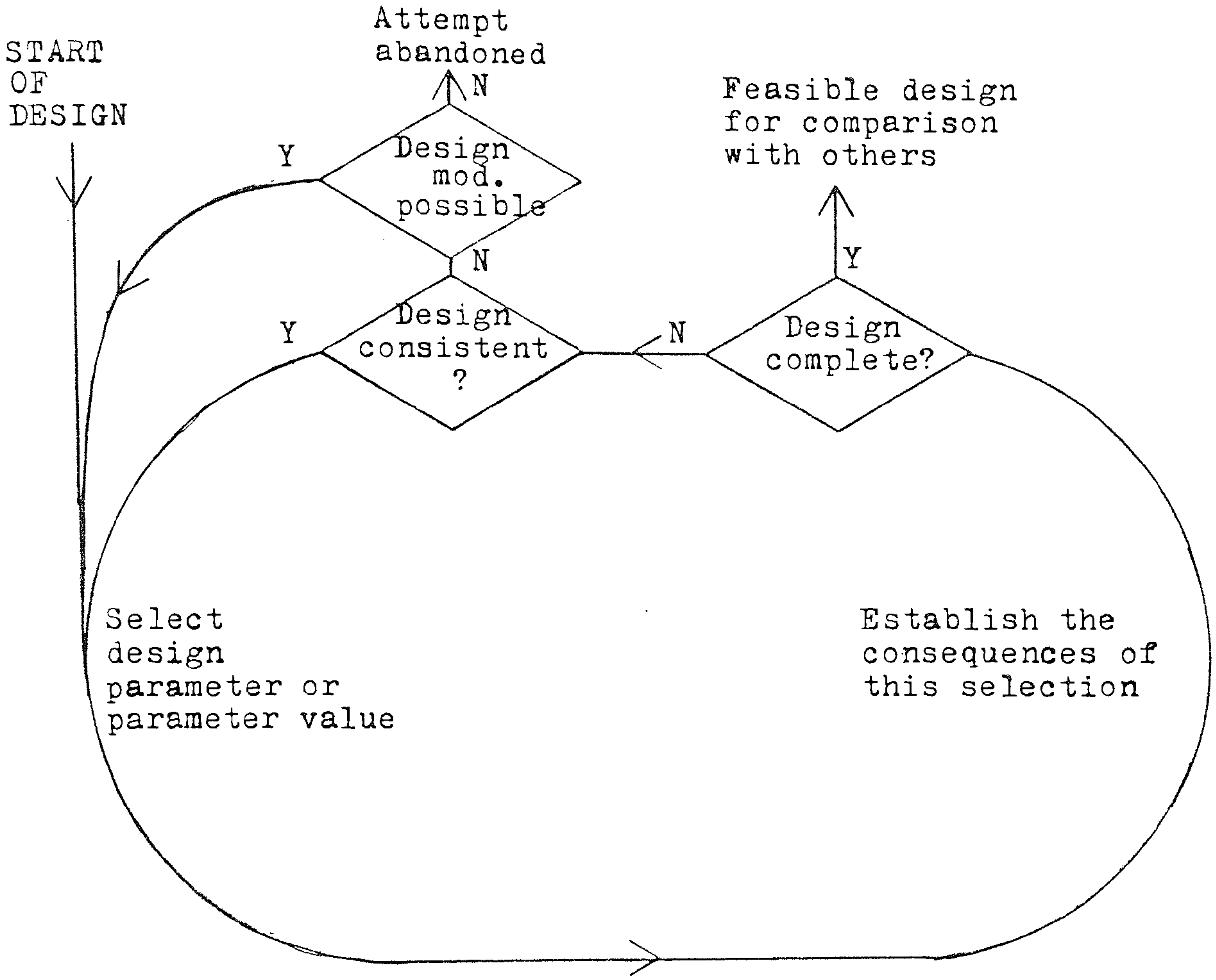


FIG. 3.1 The original design procedures of the company

The designer would first use his judgement to select various design parameters; this selection might be influenced by experience or development work and would include calculations to satisfy one or more design criteria. He would then establish the consequences of this selection; this would usually define further parameters. These consequences would be established by either drawing, referring to the design manual, or using fundamental engineering equations. The two operations described above would be repeated until either the scheme layout was complete or an incompatibility was encountered.

Early in the project I undertook the design of a new model using these procedures. This was reported in detail at the time [15]; a summary of the method adopted is shown in figure 3.2. In addition to this 'user trip', I used two further methods to evaluate the company's original design procedures:

(i) Drawings of existing pumps were examined. This not only showed the variety in designs but also made it possible to establish the critical dimensions from a tolerancing point of view.

(ii) Design attempts of other designers were examined. Particular attention was given to those schemes that were abandoned during the design phase as these highlighted problem areas.

A number of features became apparent during this evaluation.

(i) The pump design constraints fell into a number of categories; strength, stiffness, lubrication, geometric. One design decision might have to satisfy several of these.

(ii) Before drawing could be commenced it was necessary to make a large number of simple calculations to ensure geometric compatibility.

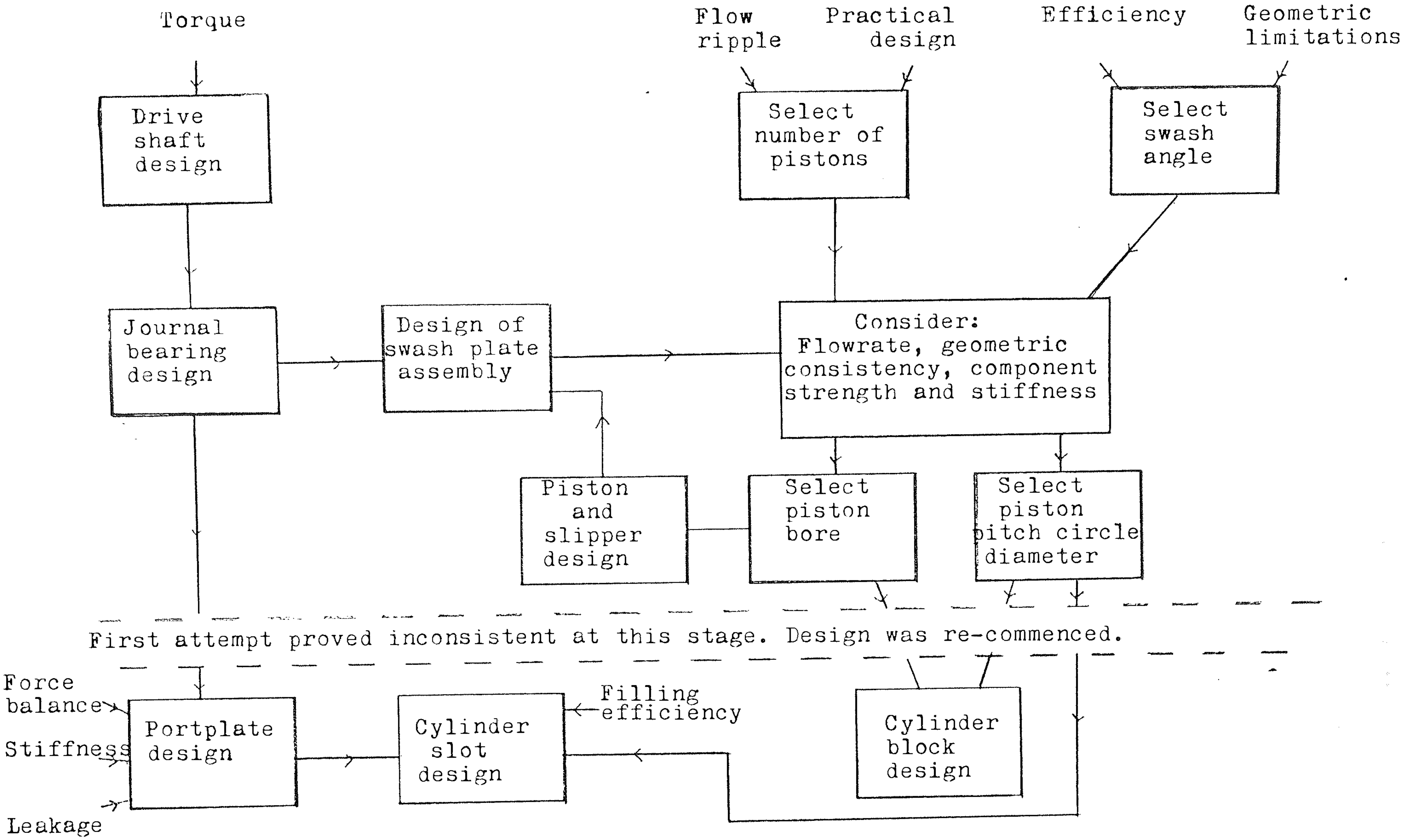


FIG. 3.2 Summary of the 'user trip' undertaken by the author

(iii) Drawing of components in their assembled positions was inadequate for assessing the effects of tolerance build up or for checking geometric consistency in the third dimension.

(iv) The design manual was useful only as a reference source; as a design guide it was inflexible and tended to over limit the designer. It also contained insufficient explanation of the design formulae to be of general use in design.

At this stage of the project a distinction emerged between complete or full design (the process described so far) and design modification. Design modification entails one or two components being re-designed subject to the constraints of those parts not altered. Although the extra constraints make this a more difficult engineering problem the designer has only a few factors to consider simultaneously. In contrast for a full design, the designer has few rigid guidelines, but must handle several constraints and criteria simultaneously.

Both full design and design modification featured in the company's work, it therefore became apparent that any improved design method would have to cater for both of these activities.

As a result of this evaluation, two ways were suggested in which the company's design procedures might be improved.

(i) To establish the origins of the design formulae used, to assess their validity.

(ii) To rationalise the designer's decision order so that a final scheme produced was always consistent.

These suggestions were put before the project committee before the final objectives were decided.

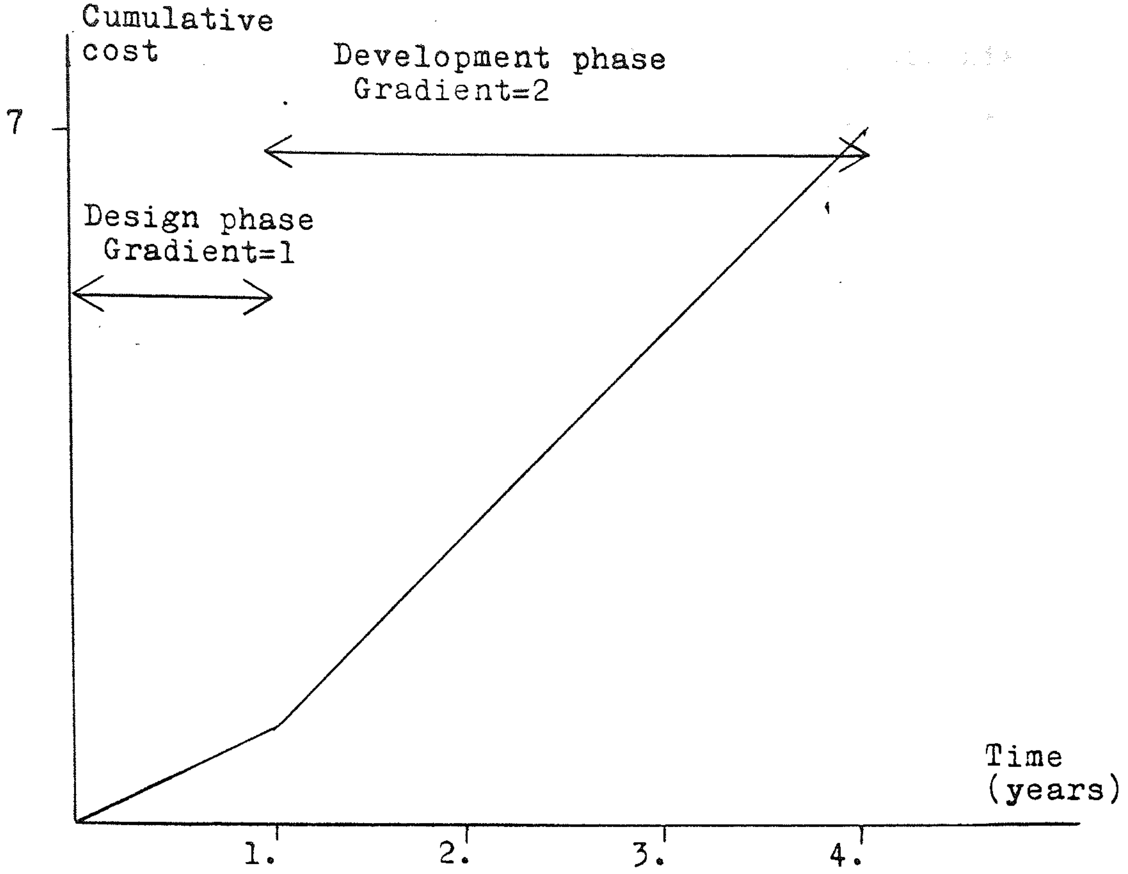
3.2. Objectives of the project

As described in Chapter 1, the main aim of the project was an improvement in the company's design method so that the design and development lead time was reduced. The company suggested a nominal reduction of from four to two years. In order to achieve this reduction,initial production drawings would have to be nearer their final form, so that time and cost could be saved in the development phase. However, as shown in figure 3.3, neither the cost nor the time taken for the design phase would necessarily have to be reduced. This is because the four years mentioned above is typically made up of less than one year's design work followed by over three years of development and design modification, and the unit cost of development time is also much higher than that of design time. Thus, although alteration to the design procedures (to reduce the amount of trial and error or eliminate the tedium of draughting) might in fact increase the design cost or time, this would be acceptable provided that the result was the more certain and systematic design procedures necessary to a shortened development phase.

This was one factor influencing the definition of final objectives for the project. Another was the disposition of the designer.

The subjects of job satisfaction and motivation were discussed in section 2.3. Naturally any modified design

ORIGINAL PROCEDURES



IMPROVED PROCEDURES

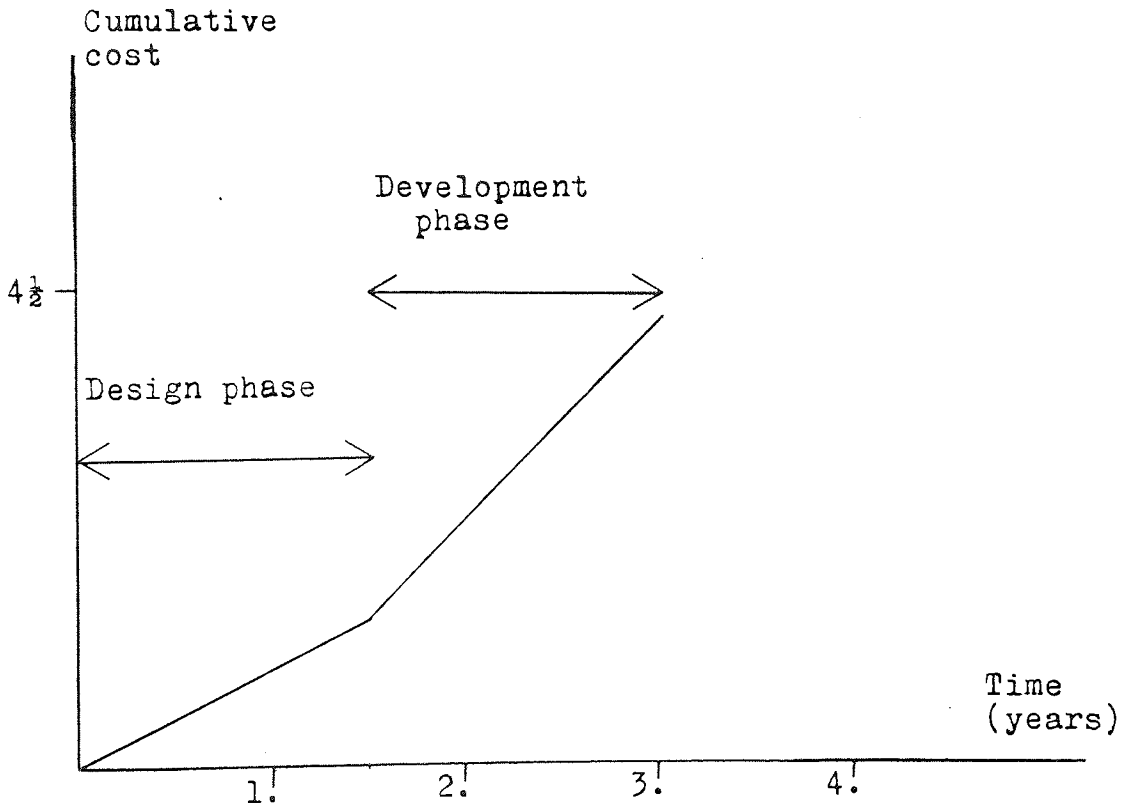


FIG. 3.3 Example costs of the design and development phases of a contract

procedures had to be acceptable to the designer, but more than this, if a designer was to be allowed to exploit his own ideas and judgement, then he would have to be able to understand and cope with the new procedures. These subjects were discussed by the project committee and during the discussion the following final objectives of the project were defined.

Final Project Objectives

(i) To devise logical and systematic procedures for designing axial piston pumps with more certainty.

(ii) To find the best way of presenting these to the designer.

(iii) To implement these procedures in the existing design office environment.

(iv) To monitor the use of the design procedures and subsequently evaluate them.

The last of these objectives was necessary to an appraisal of the project and a comparison between the original and modified design procedures.

The first two of these objectives were expanded into a number of requirements that any modified procedures had to satisfy.

(i) They had to be easy to understand and use, and require little specialised knowledge (other than of engineering) on the part of the designer.

(ii) They had to be pleasant to use so that a designer would be motivated to use them.

(iii) They had to be versatile enough to cope with deviations from normal design practice.

(iv) Updating and other improvements had to be easily implementable.

(v) The procedures had to make full use of scientific research, and experience gained through development and testing.

3.3. Procedure adopted for problem solution

The problem to be solved for the sponsoring company was defined by the objectives and requirements stated in the last section. The solution planned comprised of two major tasks; first a systematic pump design method had to be produced, and then this had to be implemented in the design office environment. These two tasks are described in parts II and III of this thesis respectively.

Before these tasks were begun, each was divided into a number of steps as shown in figure 3.4.

Essentially the first task would entail devising an ordered approach to pump design, then selecting the specific aids to pursue this approach, and finally developing the resulting procedures until the first task was complete.

The second task would entail first adopting a strategy for introducing the new design procedures, and then pursuing this through the implementation and release periods. Throughout these periods the new design method would have to be closely monitored, and maintenance and modifications made as necessary.

This would complete the problem solution and by this time the new procedures would be fully implemented and in use.

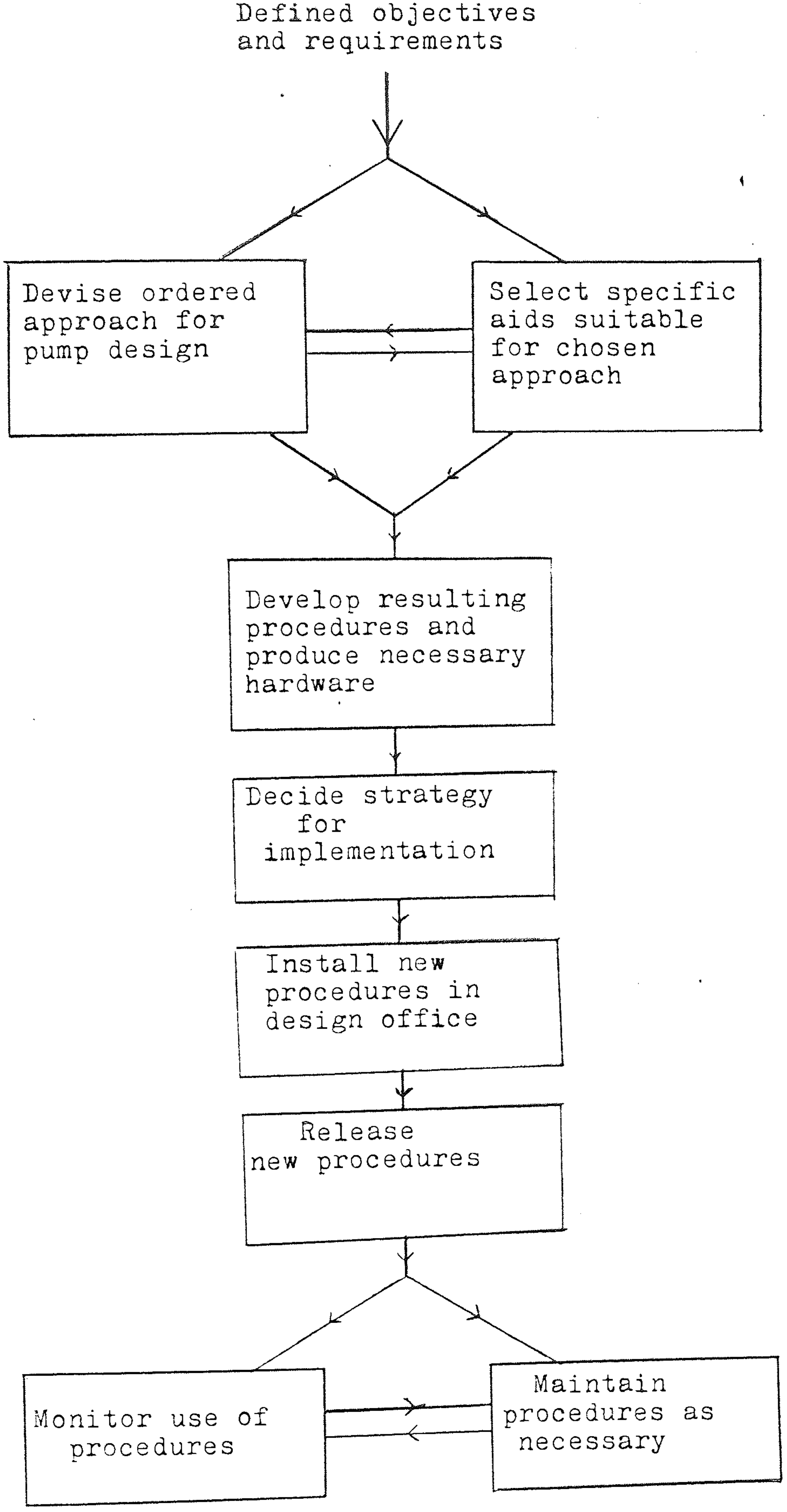


FIG. 3.4 Procedure adopted for problem solution

Having stated the objectives of the project and planned a solution, it was essential to decide on the criteria for evaluating the outcome so that the degree of success could be assessed at the end of the project.

The final result had to be a new or modified design method implemented in the company and accepted by the design office staff. The ergonomic success would be deduced from the response and opinions of the designers. The technical adequacy would be tested both by work on existing proven designs and work on new contracts. The new procedures would have to predict correctly the adequacy and performance of existing designs. However, assessment of work on new contracts posed a problem.

Even if the design and development time was reduced to two years and a new contract was commenced immediately after implementation of the new procedures, this would still not allow enough time for a full appraisal of the project success within the timescale of the project. Furthermore, the variation of lead time for different contracts would render this approach inconclusive anyway.

It would nonetheless be possible to look for trends in any new design work and compare these with previous contracts. The opinions and experience of design office staff and management would provide useful information in this respect.

The general way in which the procedures were used would supply further evaluation material. For instance, to what extent were the procedures used for design and design modification; how often, for how long, and by whom were the new procedures used; how frequent were implementation problems and how difficult were these to correct.

An examination of this information would allow a comprehensive evaluation of the new design method at the end of the project. The success of the project could then be assessed by comparing the original and new design methods. This third and final task of evaluation is described in part IV of this thesis.

The way in which these different tasks are reported in the thesis is shown in figure 0.2 in the Preface.

PART II

4.0. SELECTION OF DESIGN SYSTEM TYPE

In Part I of this thesis the objectives of the project were defined and the general solution approach was decided. This approach entailed the use of analytical design aids to improve the pump design procedures of the company. In this chapter firmer plans for the new design procedures are developed. Figure 4.1 summarises the decisions made during this development and relates these to the chapter sections.

4.1. Adoption of synthesis approach to design

As mentioned in chapter 3, the first two objectives of the project were:

(i) To devise logical and systematic procedures for designing axial piston pumps with more certainty.

(ii) To find the best way of presenting these to the designer.

These tasks were onerous as the ties between the various design criteria were numerous and involved. The aim was to guide the designer simply through successive steps, in effect to reduce a multi-dimensional problem to a more linear sequence. This suggests the need for administrative sections within the design system to co-ordinate the different design tasks. Figure 4.2 shows the different administrative levels.

At the highest level, the different design regions are co-ordinated. Below this are the levels that control the use of individual analytical tools. Lower still are levels that control the iterative procedures for analysis. The number of levels requiring designer involvement depends on the type of system adopted.

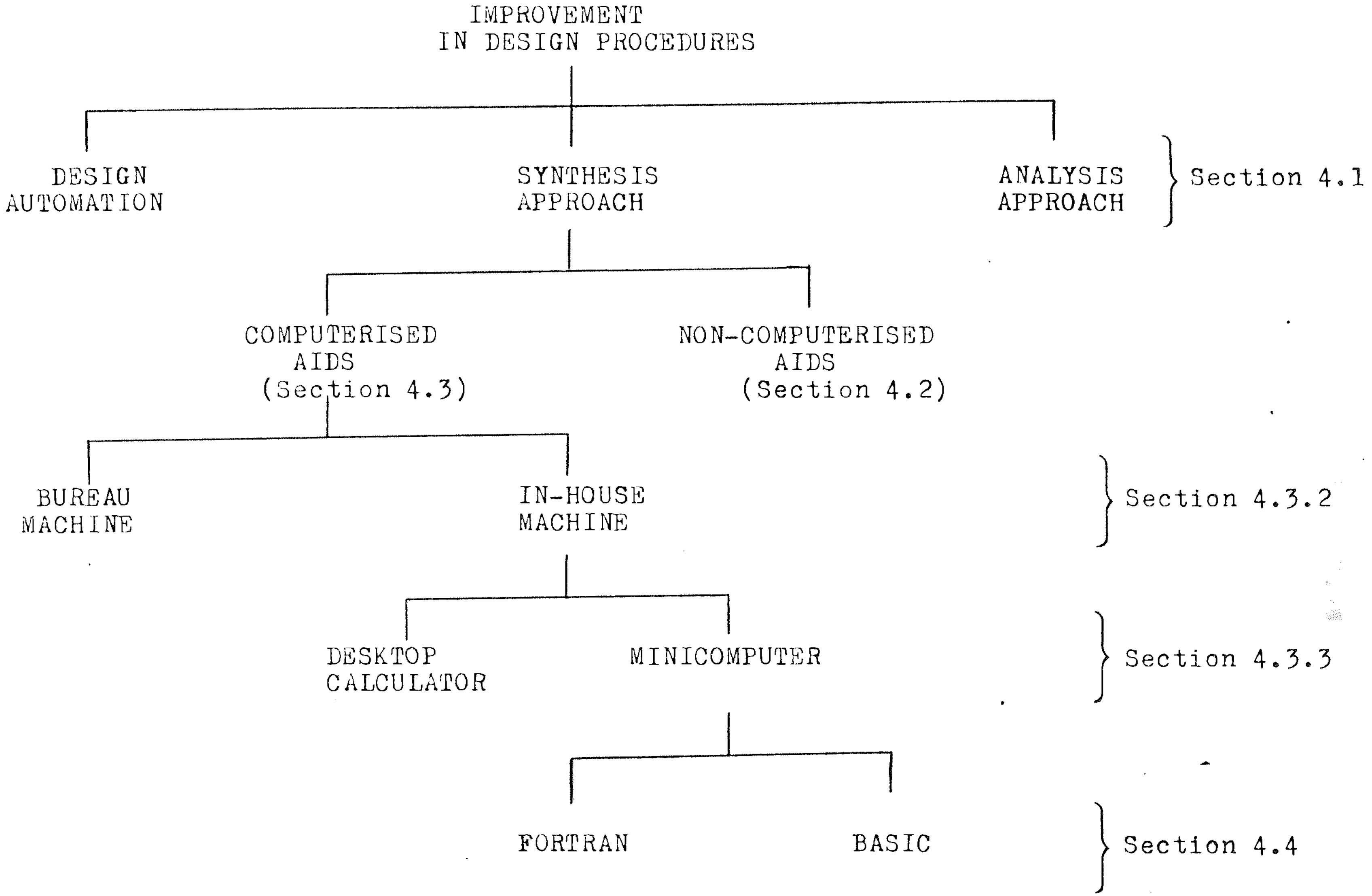


FIG. 4.1 Selection of design system type

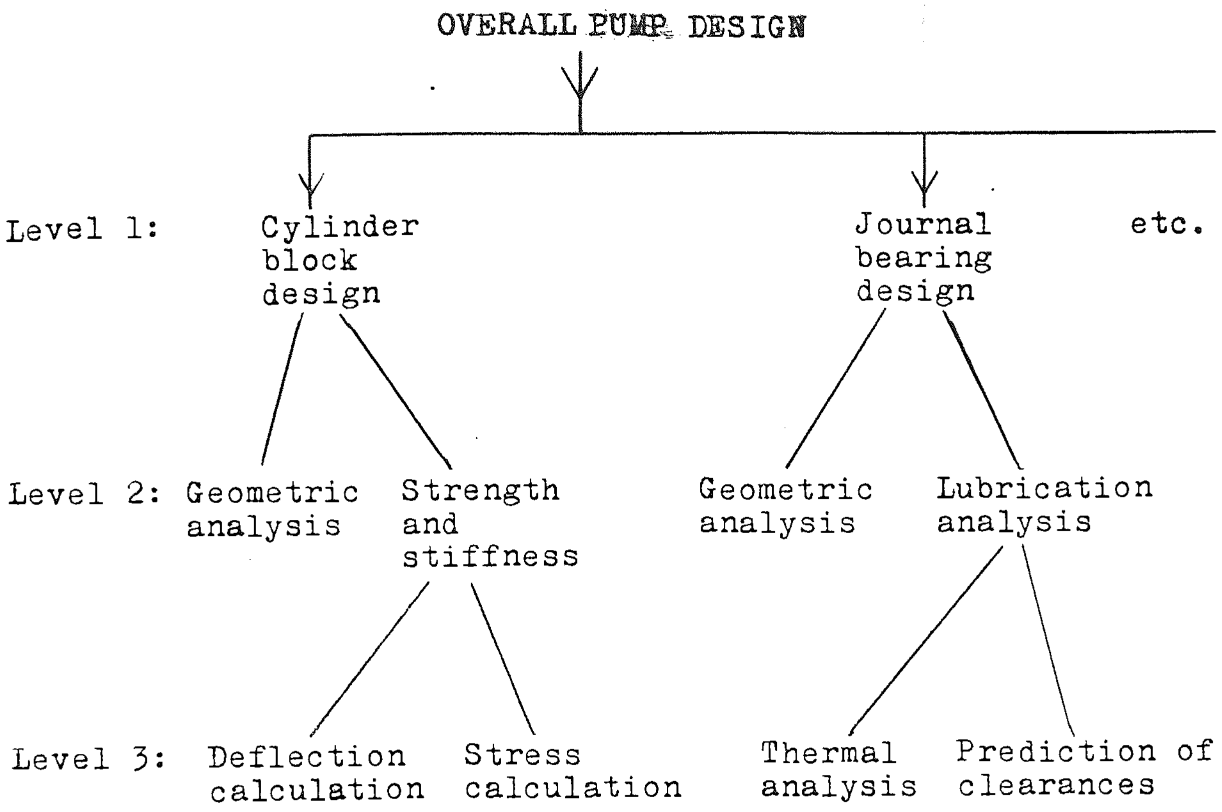


FIG. 4.2 Administrative levels to be incorporated into the design system

Parton [16] classifies two types of design system: synthesis orientated and analysis orientated. Add design automation and there are three categories to compare. These are summarised in fig 4.3. These three categories will now be discussed in turn.

According to the "design by analysis" philosophy, the designer is relied on to organise the use of the individual design aids himself. No administration is incorporated at this level. The designer is responsible for ensuring that all the necessary criteria are considered in a sensible order. This often involves a large amount of trial and error as the proposed schemes are checked against each criterion in turn. Because of the time taken to do this and the tedium involved, rather than produce a number of

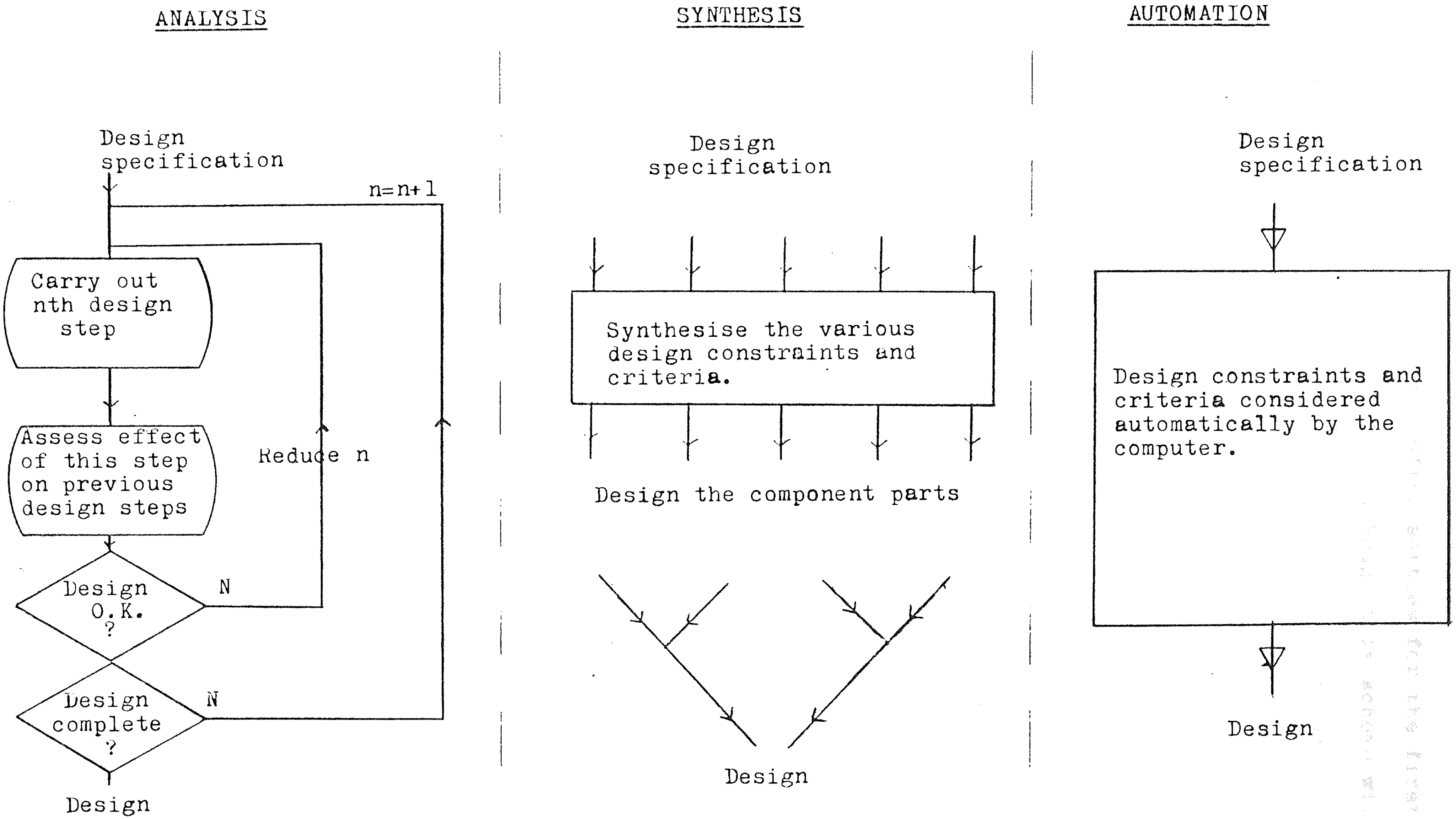


FIG. 4.3 The three categories of design system

feasible schemes, the designer often settles for the first that satisfies all the criteria. Although this scheme will often be successful, the designer never discovers how attractive other alternatives might have been, for instance, whether selection of an alternative would have allowed slackening of tolerances or use of cheaper materials.

Design automation is at the other extreme. The designer specifies the performance of the pump desired and thereafter the logic and administration is dealt with by a computer, the criteria having been specified in a suitable algorithm. In effect the designer is reduced to an operator and the real design work is done by the programme writer. It is difficult to devise algorithms adequate for designing sophisticated machinery; in addition to the technical complexity, optimising criteria have to be defined for weight, volume, shape and other such parameters. Although designers normally consider these criteria automatically, they would find it very difficult to specify them rigidly for a programme.

The "design by synthesis" category lies between the other two categories. The administration and routing are built into the system, but the designer participates in the decision making. He is required to make value judgements subject to the constraints presented by the system. This leaves overall responsibility for the design with the designer. As with design automation, the difficulty is in establishing suitable algorithms. It is essential to arrange the administrative levels to ensure that the designer considers the necessary criteria at the right time. However, once this is done, a more systematic design method results enabling more thorough evaluation of design alternatives.

Each of these categories was considered as a basis for improved design procedures. From the discussion above, the synthesis approach emerged as the favourite as it gave the best compromise between the quality of the design produced, and the time and effort required to produce it. However, before a selection was made, two further points were considered: the suitability for the designers, and the cost of the system. The following argument provoked the final decision.

As described above the analysis approach is inherently tedious and repetitive and often bores and frustrates the designer. This not only makes him dissatisfied but is also reflected in the standard of work produced. The other extreme, automation, effectively reduces the designer to the role of operator. This reduces his sense of achievement and again results in dissatisfaction. The synthesis approach is a compromise between the two. The tedious tasks are performed by the system, but decision making is left to the designer. This approach is far more attractive to the designer.

The costs of the different alternatives are difficult to assess as they depend greatly on the way in which that alternative is developed, but none of the categories were ruled out on the grounds of excessive capital cost. However, maintenance costs did feature in the argument. Maintenance costs of the analysis and synthesis approaches were thought comparable, but to maintain the effectiveness of an automated system was thought more costly. This is because modifications to an automated system are continually required if the flexibility is to be ensured. With the other two categories, certain minor modifications can be accommodated by the designer.

As a result of these arguments, the synthesis approach was selected for further development. The other two alternatives were dismissed.

4.2. Non-computerised aids

In chapter 2 the analytical aid category was divided into two groups, computerised aids and non-computerised aids. Before either of these could be adopted for the synthesis design approach, it was necessary to develop each in the context of the project to discover which was the more suitable. This section describes the development of the non-computerised group.

4.2.1. The manual-chart-calculator set

At the start of the project, a design manual already existed. This set out guide-lines for the design of the different components of the pump, and was constructed in such a way as to ensure a geometrically consistent design. However, the consistency was only achieved by rigidly specifying relationships between the different parameters. This led to inflexibility in the design procedures and discouraged the designer's innovative talents. These points were borne in mind during development of the new set.

The new set entailed the use of a manual, charts and a calculator. To save time, the set was developed just sufficiently to enable assessment of the probable adequacy, consequently, no full manual was produced. However, examples of a number of the aids devised are given in appendix B.

Figure 4.4 formed the basis for the main administrative section. This showed the relationship between the different design regions and effectively gave an advised design order. The different design regions were dealt with individually in separate sections of the manual; the relevant design equations and codes were listed in the appropriate sections. For simplicity, peripheral aids (such as check lists of bewares and tables of material costs) were not considered. However, a number of different design chart types were explored.

The overall flow chart has already been described. The use of design charts enabled simplification of both the analysis and administrative tasks. Unfortunately, the form of design charts is often limited by the form of the governing equations. This is a major limitation as the benefit of graphical presentations can be lost by the difficulty of using them. This was true of the nomograms produced for the design manual. Although they enabled graphical presentation of elaborate equations, the forms they took were not easy to interpret and use.

This problem of interpretation was partly reduced by asking the designer to use two charts simultaneously, rather than a single more complicated chart. The designer was then asked to co-ordinate these to satisfy the particular criteria in question.

This introduces the role played by the hand calculator. It was used for two tasks: evaluating the design equations given in the manual, and transposing variables from one

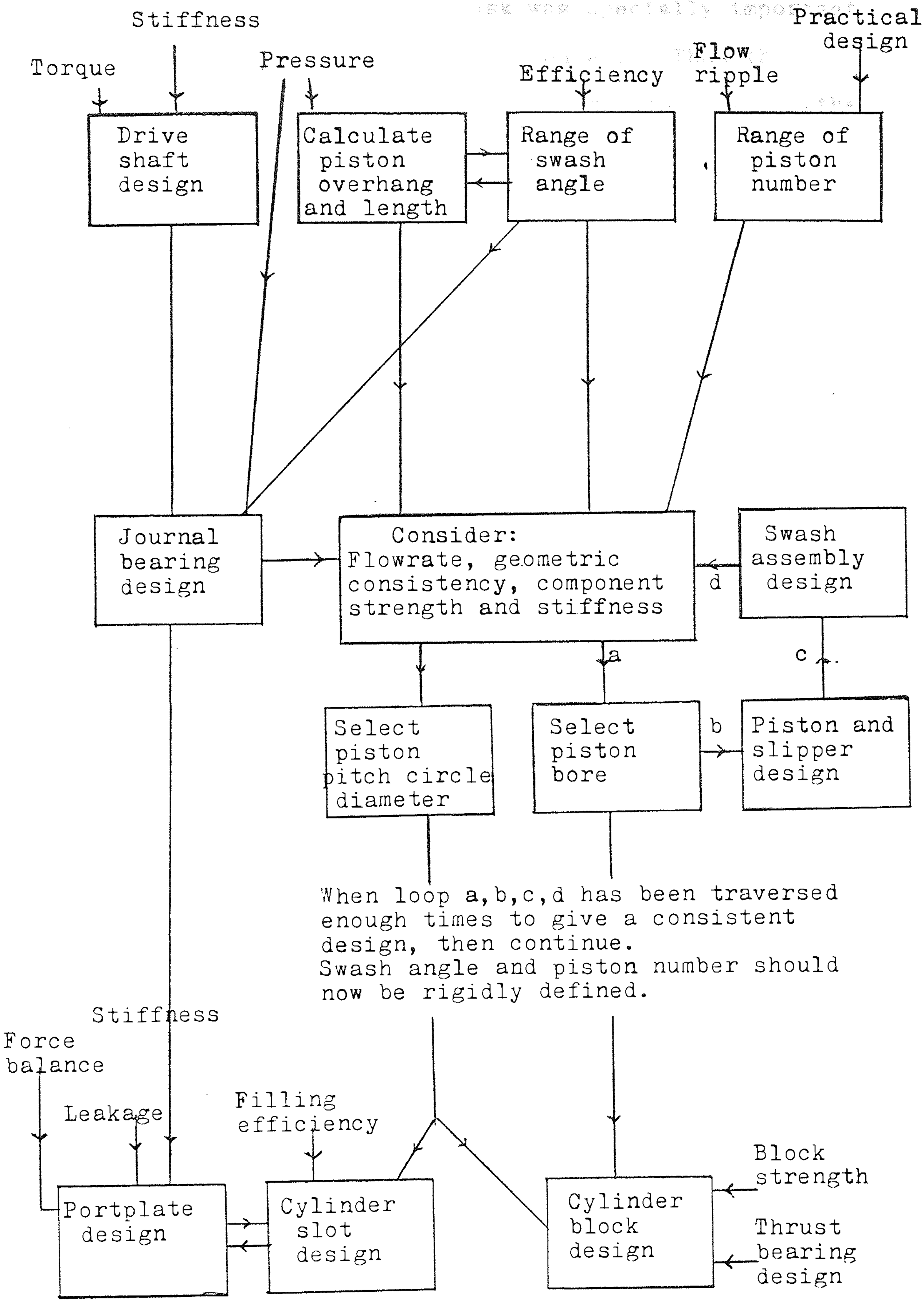


FIG. 4.4 Administrative flowchart for pump design

chart to another (this latter task was specially important as dimensionless variables were presented). Thus the calculator required was of the non-programmable type, (the use of programmable calculators is considered in the computerised aid category).

This briefly describes the arrangement of the non-computerised system developed. This is now evaluated.

4.2.2. Evaluation of the non-computerised system

Although the system described above was very basic, it was developed sufficiently to allow an evaluation of the non-computerised approach. The system showed promise, and there was scope for considerable improvement, but four major shortcomings were discovered.

(i) The administration required could only be achieved by the use of flow charts and comprehensive cross referencing and indexing. In effect the designer's progress had to be programmed into the manual by means of notes and conditional clauses. This made the system awkward and confusing to use, at least until the designer became familiar with it.

(ii) The system became lengthy because of the amount of administration required. This meant that design runs would be long, even once the designer had become conversant with the system. A design run time of 2-3 days was estimated for production of a single consistent design.

(iii) The task of maintaining such systems is usually difficult. As already described, the form of design charts often depends on the equation form. Introduction of new design criteria can cause changes to these equations necessitating major alterations to the design charts.

(iv) After production of some of the charts shown in appendix B, it became apparent that certain criteria (for instance lubrication criteria) were so complex that they could be neither evaluated rapidly nor reduced to generalised charts. Only the use of a computer enabled these criteria to be established accurately. This meant that the non-computerised approach had to incorporate an interface with a computer anyway, resulting in a hybrid system. Although this was quite feasible, it offered no advantage over the fully computerised system.

Two of the problems listed above (those of administration and maintenance) applied also to the computerised category of aid, and before a final selection was made it was necessary to develop and evaluate this second category. This is reported in the next two sections. However, as will be described, the flexibility obtained through careful programming enabled these problems to be overcome and led to the adoption of this aid category. The non-computerised aids were then discounted and effort was concentrated on developing a suitable computerised approach.

4.3. Computerised aids

This section describes the development of the computer aided approach to design that was eventually adopted in preference to the non-computerised approach described in the last section. The selection of the interactive programme running philosophy and the minicomputer class of machine is now justified.

4.3.1. Interactive computing

The object of using computer aided design systems is to find a compromise between a totally automated system and one relying too heavily on the designer's memory and stamina. The aim is to introduce the right degree of administration into the system to allow the designer to use his discretion and judgement, but to show him as early as possible the consequences of his ideas, thus preventing him from wasting his time with fruitless alternatives.

Clearly a computer can help, with the analysis at least, by performing numerous calculations very rapidly. However, the full benefit of the speed of a computer only becomes apparent if an effective dialogue is arranged between the computer and the user. This explains the increase in popularity of on-line systems over the last ten years.

On-line is the term used to describe the situation whereby the user can communicate directly with the computer and normally receives a reply within seconds. The cost of computer installations means that on-line systems can only be justified economically by the use of time sharing. With time sharing several computer users are served simultaneously by one computer. The computer performs a loop, servicing each user in succession, however, because the speed of calculation is so fast, it completes each circuit in a matter of milli-seconds. Even allowing for periods of pure calculation, each user receives a response from the computer within a matter of seconds. Popell [17] describes these concepts more thoroughly.

This kind of system enables interactive design work; that is, design work in which a rapid dialogue takes place between the designer and the computer during which the designer's decisions are evaluated and the consequences established. The necessary administration for the design procedures is programmed into the computer software. In effect the resulting programme is a computerised design manual, but instead of telling the designer to: "Turn to page 64 if the piston neck stress is too large and the bore cannot be reduced without increasing the pitch circle diameter", this logic is programmed into the system.

These advantages led to the adoption of the interactive programme running philosophy. It remained, however, to compare the different computerised aids in this class.

4.3.2. Minicomputers versus mainframes

Computers can be classed according to their memory* size and cost into two groups, minicomputers and mainframe computers. Broadly speaking a minicomputer does not exceed a memory size of 150K or cost more than £80,000 (1978 prices), a mainframe is not less than 200K in size

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* See Glossary of terms for definition.

and does not cost less than £100,000.

Minicomputers are often found in individual company departments. However, if a company is affluent enough to own its own mainframe, then it usually constitutes a separate company department, offering a service to other departments.

The use of mainframe computers usually takes one of two forms. Either the computer is on or near to the company premises and readily available (in-house), or it is remote (often this is a computer bureau) and connection is achieved through a telephone link.

For this project no local mainframe was available. The choice was thus between buying a minicomputer and using a bureau. (Desk top calculators are considered separately in the next section). Table 4.1 compares the costs of these two alternatives.

When hiring computer time from a bureau, three types of costs are incurred; connection charges paid to the bureau for the privilege of being on-line, 'mill time' charges depending on the amount of actual computer time used, and finally communication charges paid to the G.P.O. for the use of the telephone link. The main costs incurred with the minicomputer are the capital costs and maintenance costs. As shown in table 4.1 the minicomputer is cheaper for on-line use.

The following points relate to this table:-

(i) The cost rate for the minicomputer is obtained by assuming that it is in use continuously 8 hours/day. (This is a reasonable average

MINICOMPUTER		BUREAU COMPUTER	
Capital cost £20000			
	£		£
Cost depreciated over 4 years	5000/yr	Communication charges	7.20/hr
Maintenance cost at 10%	2000/yr	Connection charges	15 /hr
Extra staff to manage system	10000/yr	Estimated "mill time" costs	5 /hr
Total	17000/yr		
Use: 200 days/yr			
Cost/hr $\frac{17000}{200\text{x}8}$	£11/hr	Cost/hr	£27/hr

(costs based on Jan 78 prices)

TABLE 4.1 Cost comparison for interactive use: Minicomputer v Bureau Computer as the computer may be used overnight, or it may be used time-shared to serve several users).

(ii) The rate for the bureau service is determined by hire charges alone. This does not include the extra cost of peripheral equipment that might be desirable (e.g. graphics terminals, line printers).

This comparison showed that the minicomputer was economically the more attractive alternative. However, the company had to consider two further aspects before the minicomputer could be thought a viable proposition. The size had to be large enough to accommodate the design software envisaged. An estimate of 20K was made based on programming experience. This criterion was satisfied by most minicomputers. Also the company had to be prepared to make a commitment to software development and maintenance to supplement the programme libraries and service offered by the manufacturer. This was accepted by the management. The minicomputer was then accepted as being preferable to the mainframe alternative.

4.3.3. Minicomputers versus desk top calculators

The range of minicomputers and desk top calculators on the market is very large; in the last year or so the two machine classes have become virtually indistinguishable. A particular machine should now only be classed according to its memory size and calculation speed. However, to simplify the comparison of the different types, the distinction that existed at the start of the project, between the classes, is kept in this thesis. With this in mind the two classes were each considered as a basis for the modified design procedures. Table 4.2 shows the salient features of the two classes as they related to the project.

The first two points in the table appear to be in the favour of desk top calculators. Certainly these machines enable rapid, more straightforward programme development; this is of particular benefit to the novice programmer. However, this tends to result in programmes with a stereotyped form of interaction; these are unattractive as design tools. Just as there is an art of producing design manuals and nomographs, there is an art of writing interactive programmes and it is a mistake to underestimate the difficulties of producing effective software. (This point is expanded later in the thesis). The minicomputer, though more cumbersome to programme, allows much more flexible interaction to be built into the programmes and enables production of more effective design tools.

The small memory size of the desk top calculators was of great importance in this project. The estimated size of programmes for stress analysis and lubrication analysis was about 20K, too large for the desk top machines.

Points (v) and (vi) in table 4.2 were of particular significance to the company as other employees working on a different project were then looking at the feasibility of automating the control and data logging for experimental test rigs. This made the alternative of a single multi-user minicomputer to serve the tasks of design work and

	DESKTOP CALCULATOR	MINICOMPUTERS
i)	No specialised staff needed to run the machine.	Staff with an understanding of computers needed to run the machine.
ii)	Effective interaction is designed into the machine to facilitate both programme development and programme running.	The degree and type of interaction required has to be programmed in during the system development. The programme development is more tedious but the interaction achieved in the final design procedures can be very effective.
iii)	Maximum programme size limited to about 8K.	Programme sizes of up to 20K possible.
iv)	Secondary storage of data is on cassettes or cartridges which have an access time of seconds. Hence the designer has to wait longer for the computer to recover this data.	Secondary storage of data is on disk which has an access time of milli-seconds. Thus the designer has less time to wait for the computer to recover this data.
v)	Machines usually dedicated to a single user.	Option of multi-user capacity on most machines by means of time-sharing. Thus two or more designers may use the system simultaneously.
vi)	Other uses limited.	In addition to design work, the same computer may be used for other tasks such as data-logging and test rig control.
vii)	Cost from £10000 for a suitable system.	Cost from £20000 for a suitable system.

(Costs based on Jan 78 prices.)

TABLE 4.2 Comparison of minicomputer and desktop calculator.

testing work very attractive. Cleife [18] argues this point more thoroughly. The project committee considered that these benefits merited the extra cost of the minicomputer.

The desk top calculator was the last aid to be considered in the computerised category. (The programmable hand calculator was regarded as a much cheaper, but far less versatile variant of the desk top machine and therefore also inadequate). A decision was thus made, to use a minicomputer with multi-user capacity as a basis for the design system. This was the framework to which subsequent project work was directed.

4.4. General programming philosophy

In this final section of the chapter, the basic programming philosophy adopted for development of a computerised design system is expounded. Three topics are considered in turn, the question of programme loop size, the use of graphics, and the choice of programming language.

4.4.1. Programme loop size

In section 4.1 the possibility of a totally automated design system was considered, but rejected. Figure 4.5 shows a flow chart suitable for such a system. In this flow chart there are a number of iterative loops of different lengths and we might expect to be able to optimise the programme loop sizes for efficient programme operation.

In the case of a computer aided system, (the option adopted in section 4.1), the situation is more complex as the designer is required to interact with the computer at

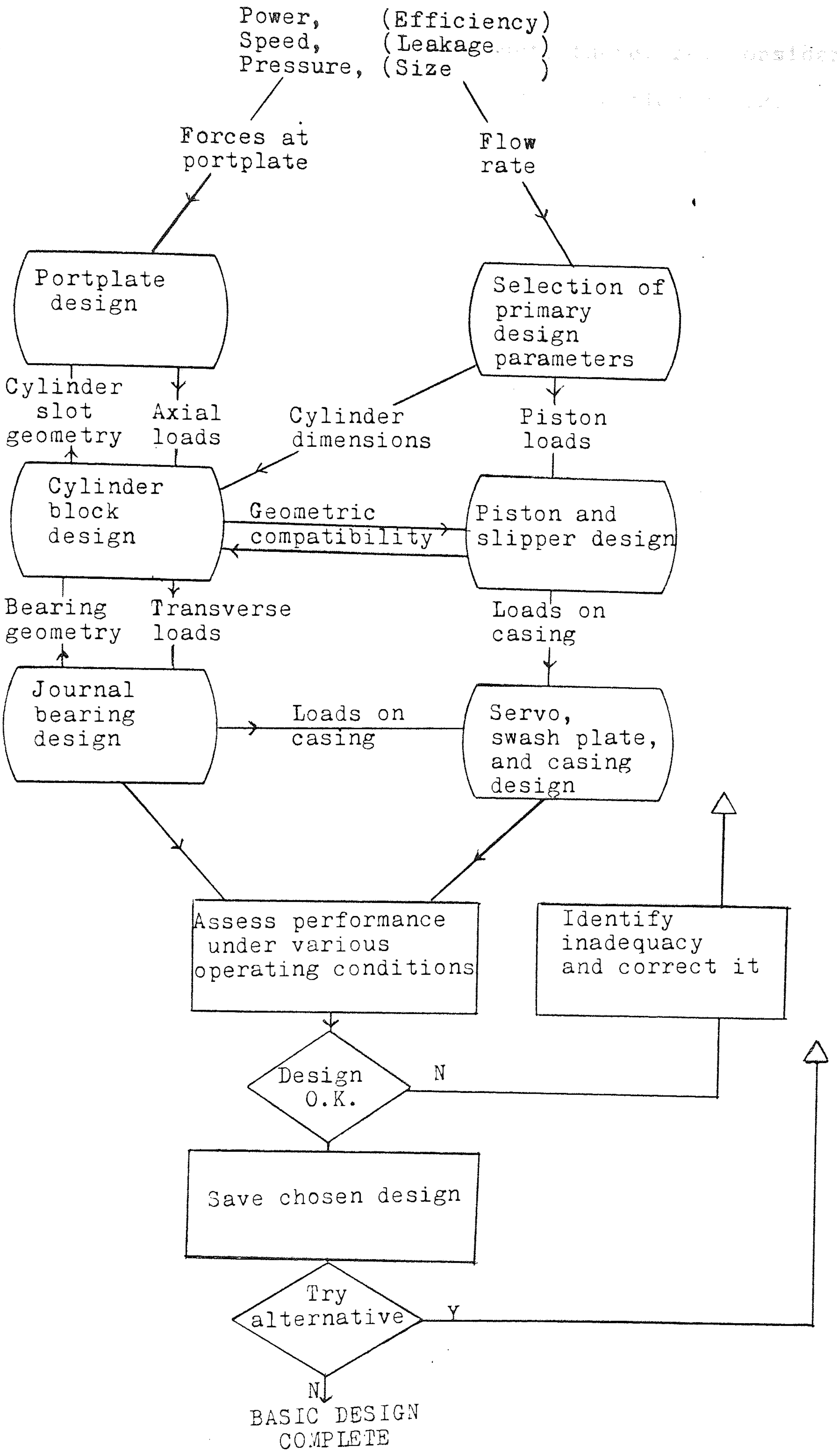


FIG.4.5 Flowchart for totally automated pump design

certain stages of the loop. We must, therefore, consider, the psychological factors discussed in section 2.3.2.

Suppose that a designer successively made a number of decisions pertinent to the pump design only to be told at the end of a long sequence that the design was inadequate. This would be both frustrating for the designer and time consuming. It is desirable to advise the designer of the adequacy of his decision as soon as possible after he has made it, so that he may alter it if necessary. Indeed, if possible the designer should be informed in advance of what will and will not work. To achieve this, the loop in which the designer appears to be must be small, (although the computer may have to perform many iterations for each loop).

These points will now be demonstrated using two proposals made early in the project for preliminary pump design programmes. In the preliminary design, the designer has to decide values for the primary design parameters; piston number, swash angle, piston bore and piston pitch circle diameter. These are the parameters which define the flow capacity of the unit and also the shape of the running gear. Once decided these parameters restrict all other design decisions.

Figure 4.6 shows the first proposal. As can be seen, the salient design regions are tackled in turn and the designer is asked to modify his choice if at any stage the design proves inconsistent. A distinctive feature of this proposal is the HELP facility whereby the computer is requested to pursue an inconsistent design, choosing reasonable values for further required data and finally

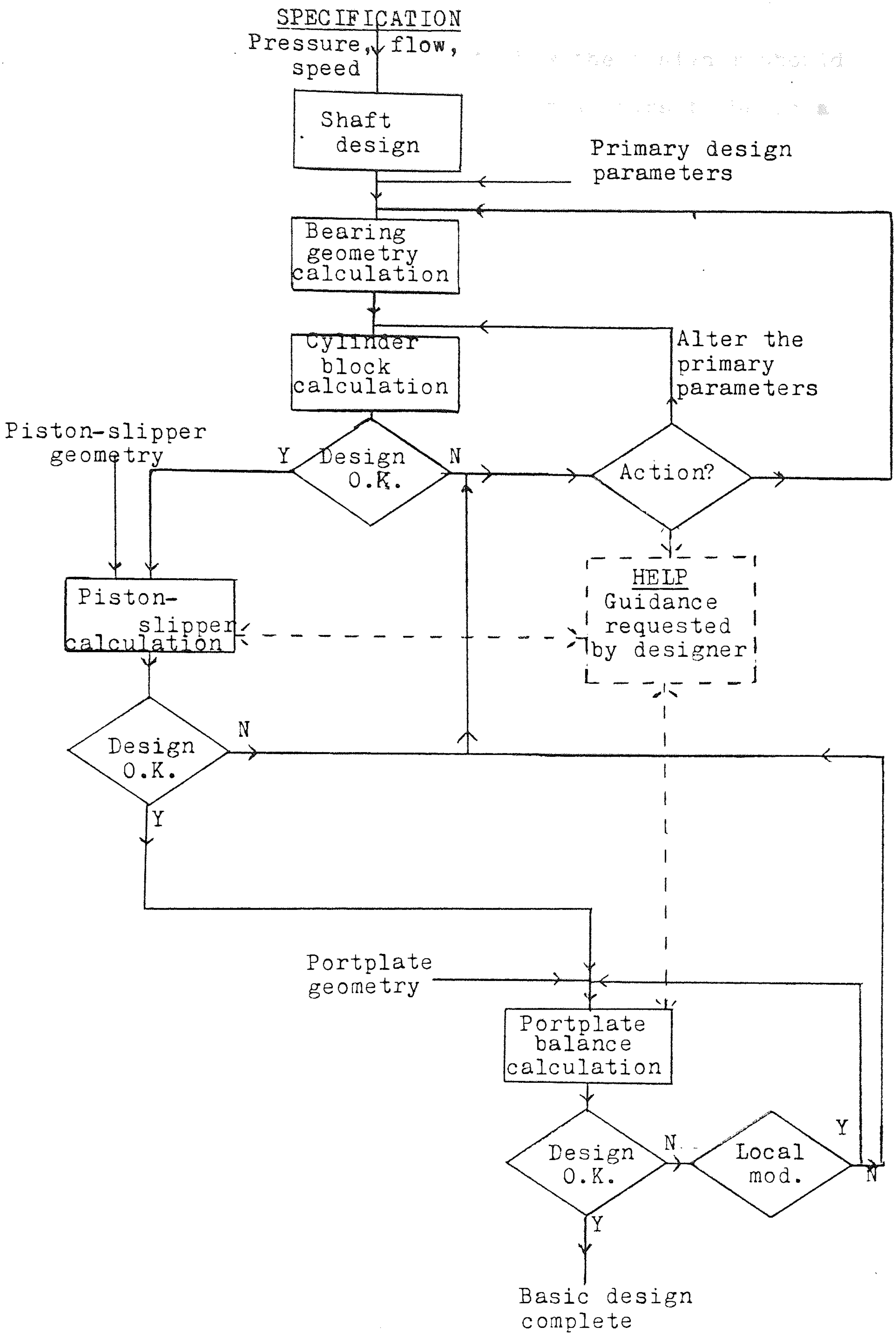


FIG. 4.6 Flowchart of the first proposal for a pump design feasibility programme

returning with a suggestion as to how the designer should alter his choice. Thus, the designer appears to be in a small loop. However, it is possible that in some circumstances, even after taking the computer's advice, the designer would find it impossible to achieve a consistent design. As mentioned earlier, this would be both frustrating and time consuming.

Looking at the flow chart, it is not obvious how the programme could be improved by the use of different loop sizes, and in principle the HELP concept seems sound.

In fact the problem is in the serial structure of the programme. The design regions should not be considered successively but rather simultaneously. This was the philosophy of the second proposal.

A flow chart for the second proposal is shown in figure 4.7. The first part of the programme is similar to that of the previous proposal, but subsequently the chart splits into a number of parallel loops. The designer may execute these as often as he likes and in any order. After executing them all, he can see immediately which constraints are limiting his choice of primary design parameters, and only at this stage need he choose values for them.

Both serial and parallel loops were used in the design system developed. The parallel loop philosophy was used predominantly in the preliminary design programme in which the primary design parameters are selected.

4.4.2. Use of graphics

The use of graphics is essential in the parallel loop philosophy described in the last section as it is the

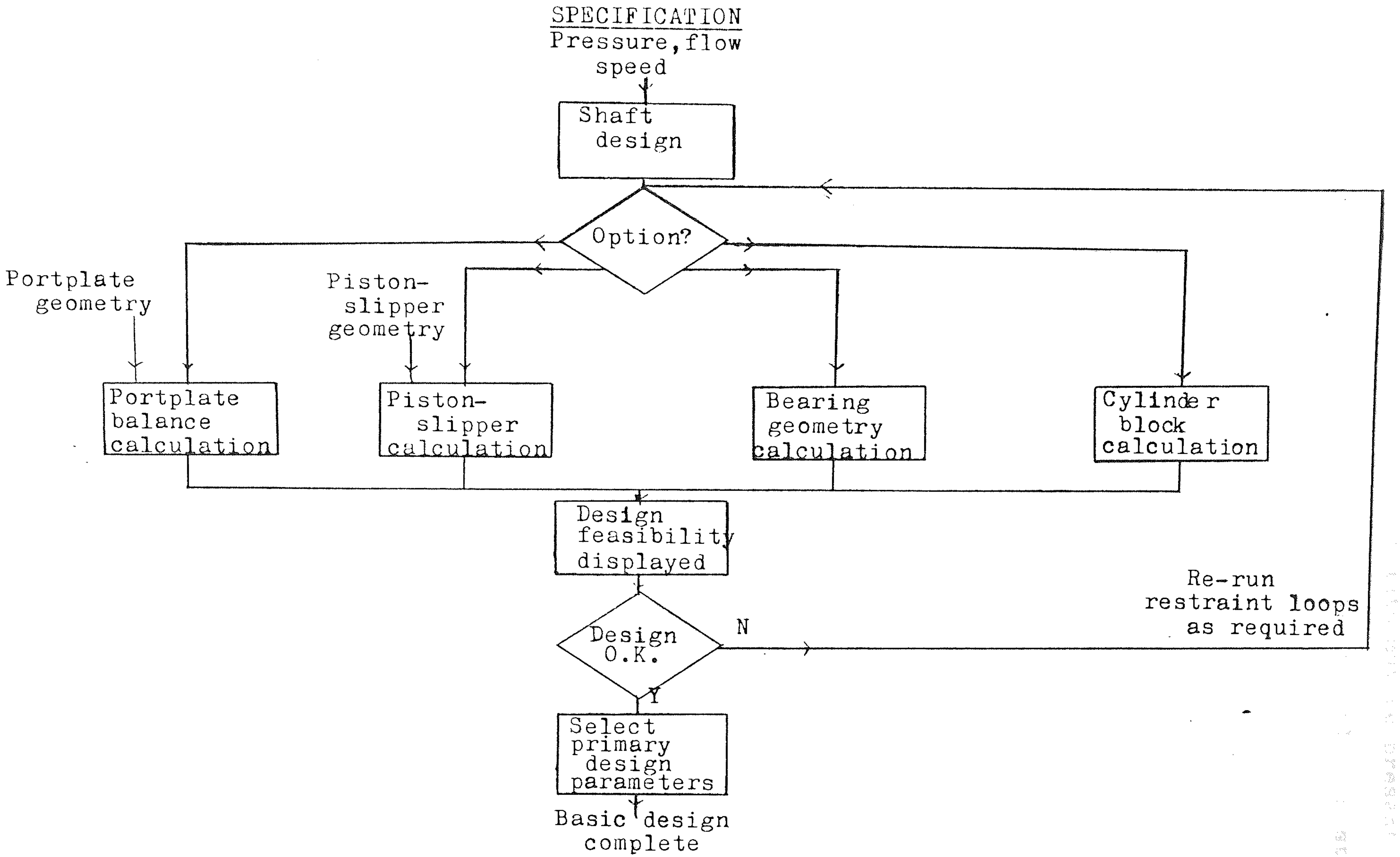


FIG. 4.7 Flowchart of the final proposal for a pump design feasibility programme

clearest way in which several constraints may be presented simultaneously. Graphic presentations are useful in most design programmes. However, there is a limit to the amount of information that can be represented in two dimensions and so the form of displays has to be chosen carefully.

In effect we are adding extra dimensions and flexibility to the kinds of design chart discussed in section 4.2.1, but now we can arrange to display only that chart of specific interest to the designer at the time, rather than some generalised or non-dimensionalised version. We can also enable him to quickly repeat displays with selected parameters modified.

In this way the graphics can be kept clear and simple and so help rather than confuse the designer.

4.4.3. Programming language.

At an early stage of the project it was necessary to decide on a language to be used for the design system. A number of computer languages, Fortran, Algol, Basic, APL, are well suited for engineering programmes. However, only two alternatives, Fortran and Basic, were seriously considered. There were two reasons for this. First the language selected had to be available on the University of Aston computer so that early system development could be done there prior to purchase of a minicomputer. Secondly the language had to be offered by a number of minicomputer manufacturers, so that this did not later impose a restraint on the selection of the minicomputer. Only Fortran and Basic satisfied these criteria.

These two languages were originally intended for different purposes. Basic was written for on-line programme development and running whereas Fortran was a more technical language not specifically designed for interactive use. However, since their conception, boundaries have shifted somewhat and now Basic is sometimes used off-line and Fortran on-line. The comparison shown in table 4.3 shows the main points that were considered when selecting the language.

To consider these in more detail, the first two are concerned with input/output. Although Basic is simpler in these respects, it is not difficult to develop extra software to bring Fortran to the same standard. (Essentially the aim is a system which accepts unformatted data and copes sensibly with erroneous input).

The compulsory numbering of statements in Basic is a disadvantage as it makes programme development and maintenance more difficult. Many Basic systems incorporate automatic numbering and conventional editing but this then leads to the problem of programme compatibility between different Basic machines. In practice the statement numbering also limits the maximum size of Basic programmes. With Fortran the maximum size is only limited by the memory size of the computer.

The facility of mnemonic variable names in Fortran is a benefit as it results in programmes which are easier to understand and maintain and lends itself to standardisation of variable names.

Finally the benefit of being able to input arithmetic expressions directly in Basic can be off-set by using a

	FORTRAN	BASIC
i)	Requires formatted input and output.	Unformatted input and output allowed.
ii)	Programmes fail if erroneous data is entered.	Such data is re-requested by the programme.
iii)	No limit to number of programme statements.	All statements must be numbered.
iv)	Mnemonic variable names allowed.	Choice of variable names more limited.
v)	Cannot be used in desktop calculator mode.	Can be used in desktop calculator mode.

TABLE 4.3 Comparison of 'fortran' and 'basic' programming languages

hand calculator in conjunction with a Fortran programme.

After considering these factors and also the degree of standardisation and technical flexibility that has been achieved with Fortran over the years, this language was selected. Programme development was then begun in earnest.

As far as the designer is concerned, this decision has little relevance as naturally the dialogue between the design system and user must be in English with error-proofed input and output. However, the decision was significant for system development. This is the subject of the next chapter.

5.0. CONCEPTION AND DEVELOPMENT OF THE 3-STAGE C.A.D. SYSTEM

Having decided which type of system is desirable, we now pursue the construction of this system justifying, where necessary, the methods used. This chapter summarises the stages of development in chronological order, describing the aims and benefits, and finally reviewing each section. Detailed discussion of the operation and interaction of the programmes is saved until chapter 6. All the development described in this chapter was done on the University of Aston ICL 1904S computer.

5.1. The Design Feasibility Programme

In the last chapter a flow chart for the preliminary design of pumps was described (fig 4.7). This was intended to allow the designer to assess the feasibility of satisfying the design specification. The programme developed is now described in more detail.

5.1.1. Aim of the programme

The aim of the feasibility programme is to present the constraints on the design simultaneously so that a designer can establish the feasibility of achieving a given specification. The programme developed first helps the designer to select an adequate drive shaft, and then presents the combinations of bore, pitch circle diameter, swash angle and piston number that will give a consistent design. As already described, these four variables are the primary design parameters and must be chosen before the design can be pursued further. This kind of programme is ideally suited for interactive use, with the designer effectively inside the programme loops. He may thus repeatedly modify his decisions to explore design alternatives and when he is convinced that he can design within the constraints, then he may choose values for the primary design parameters and proceed to the next stage of the design.

5.1.2. The Feasible Design surface

Although a detailed description of the nature of interaction is given in the next chapter, for clarity the feasible design surface developed in conjunction with the feasibility programme is discussed here.

Figure 5.1 shows how for a specified flow capacity and piston number, possible designs can be represented by a surface in three-dimensional space. (There will be a different surface for each choice of piston number). Choosing a point on the surface automatically defines the bore, pitch circle diameter, and swash angle of the pump.

If we can now represent the design constraints as functions of bore, pitch circle diameter (PCD), swash angle and piston number, then we can construct additional surfaces which will cut the feasible design surface and hence restrict the allowed area in which we may design.

This is all very well, but it would be difficult to present such a three-dimensional model to the designer even using computer graphics. The surface must be reduced to two dimensions. There are two ways in which this can be done:

(i) By combining two of the axes and plotting (say) bore/PCD against swash angle;

(ii) By taking a projection of the surface onto a plane and representing the third variable

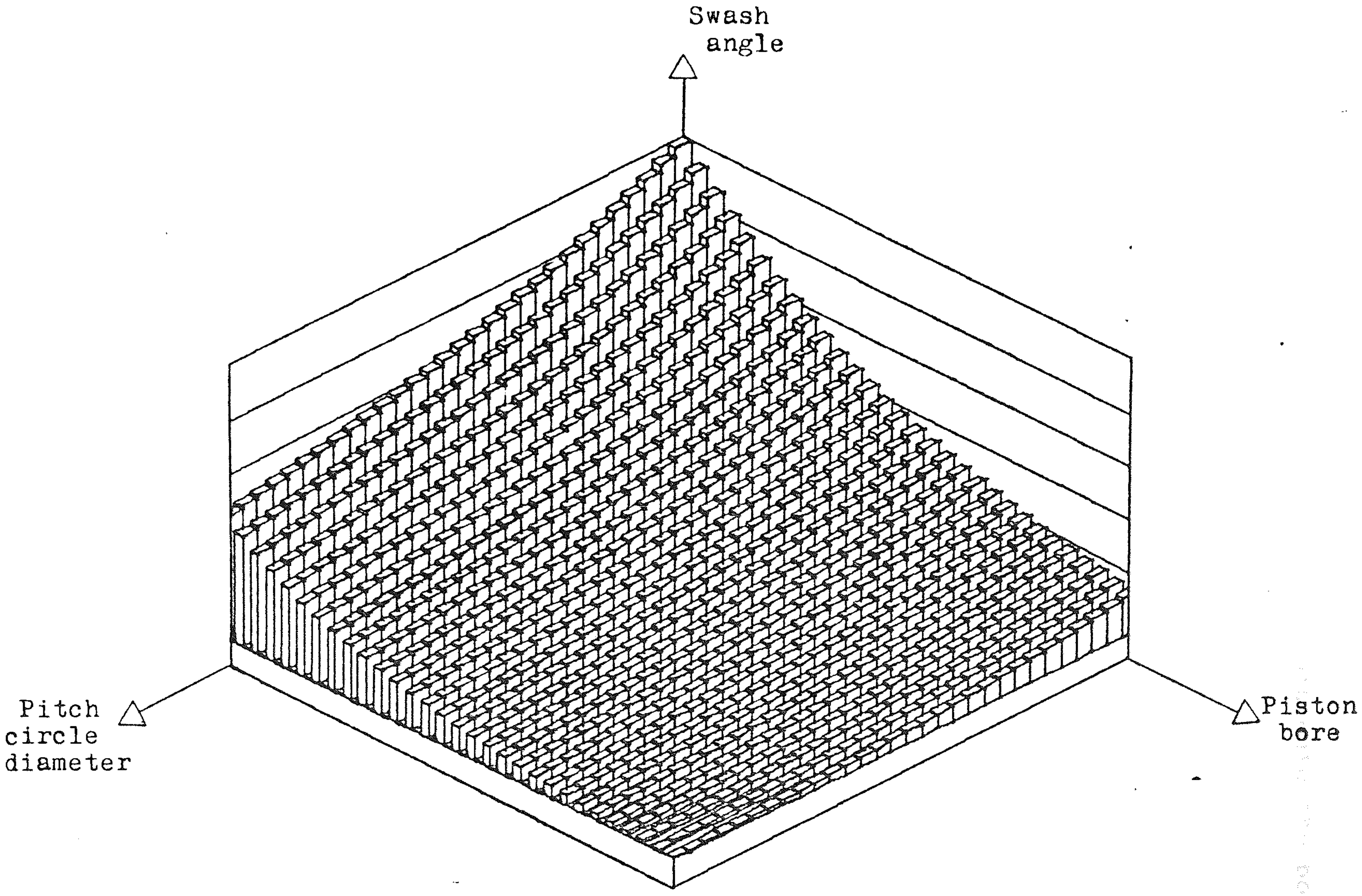


FIG. 5.1 Three-dimensional representation of feasible designs for a given specification

using contours.

The method chosen was to project down onto the bore-PCD plane for the following reasons:

(i) The designer can, in this way, retain a feel for the size of the design as the bore and PCD are depicted separately;

(ii) It is more important to have bore and PCD graduated on the axes than swash angle, which need only be estimated to half a degree at the preliminary design stage.

The result of reducing the surface to two dimensions in this way is shown in fig 5.2.

5.1.3. Benefits of the programme

The benefits of the programme ensue from the rapidity with which it can be run. The feasibility of achieving a given specification can be quickly assessed. The programme can therefore be useful in the following situations:

(i) When undertaking a new design, instead of obtaining a single consistent design, several alternatives can be pursued for comparison;

(ii) The programme can be used to evaluate existing designs. In particular it may be useful to run the programme whenever a design is modified to remind the designer of the constraints. This should also allow the designer to see whether it was originally over-designed.

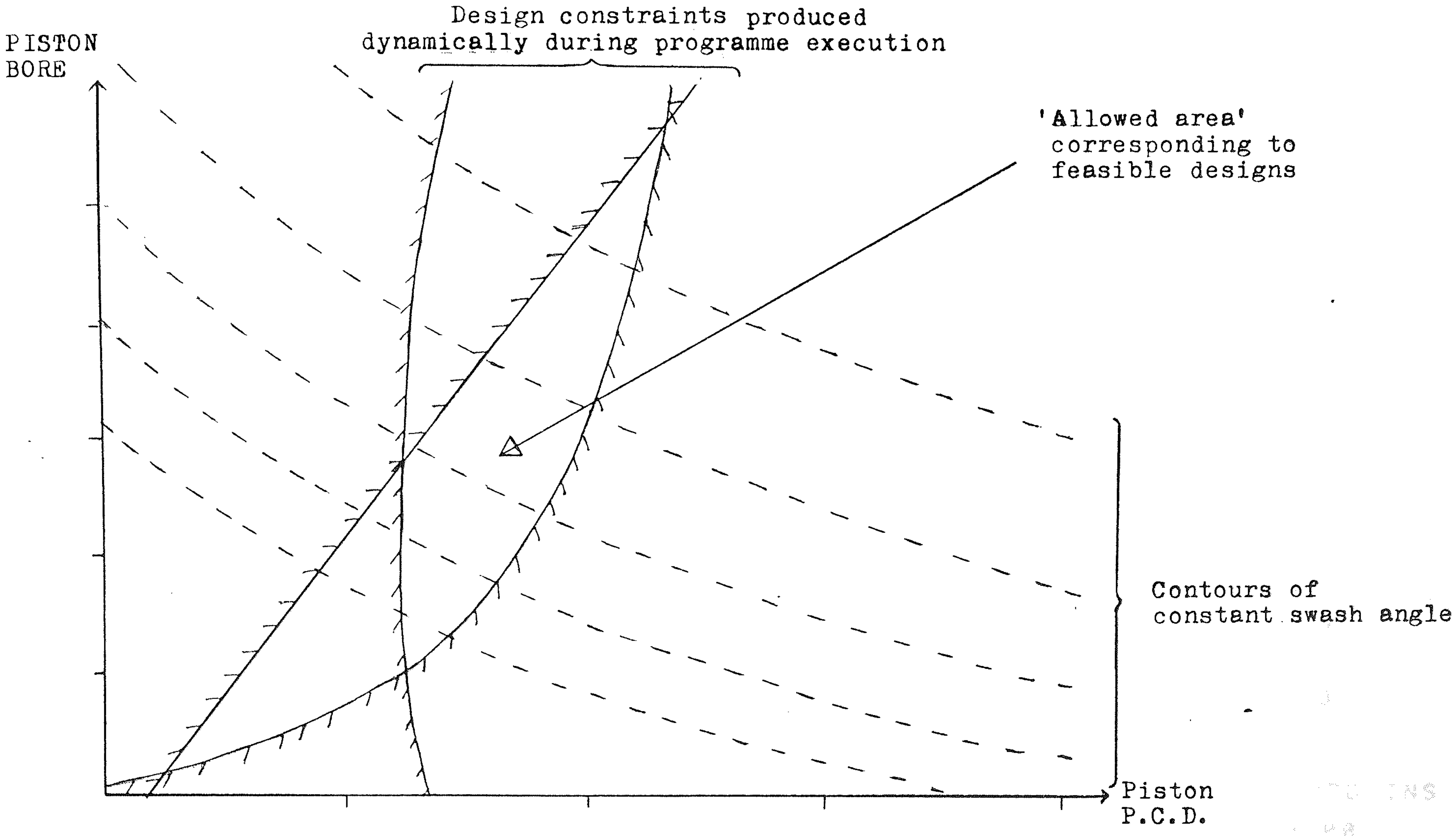
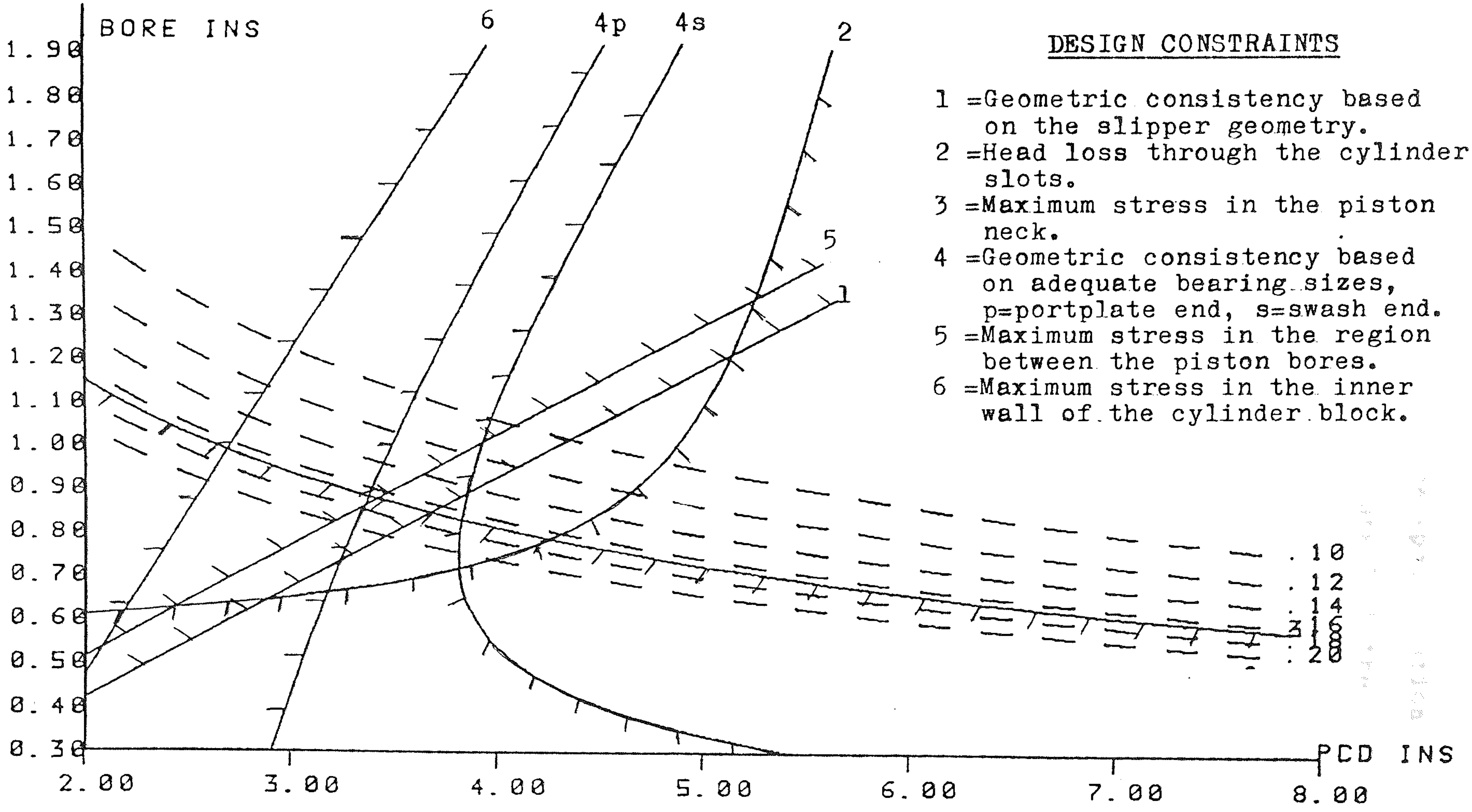


FIG. 5.2a The Feasible Design chart



DESIGN CONSTRAINTS

1 =Geometric consistency based on the slipper geometry.
2 =Head loss through the cylinder slots.
3 =Maximum stress in the piston neck.
4 =Geometric consistency based on adequate bearing sizes, p=portplate end, s=swash end.
5 =Maximum stress in the region between the piston bores.
6 =Maximum stress in the inner wall of the cylinder block.

FIG. 5.2b A more elaborate Feasible Design chart

(iii) By artificially uprating the specification of a unit the designer can establish the scope for uprating a particular design.

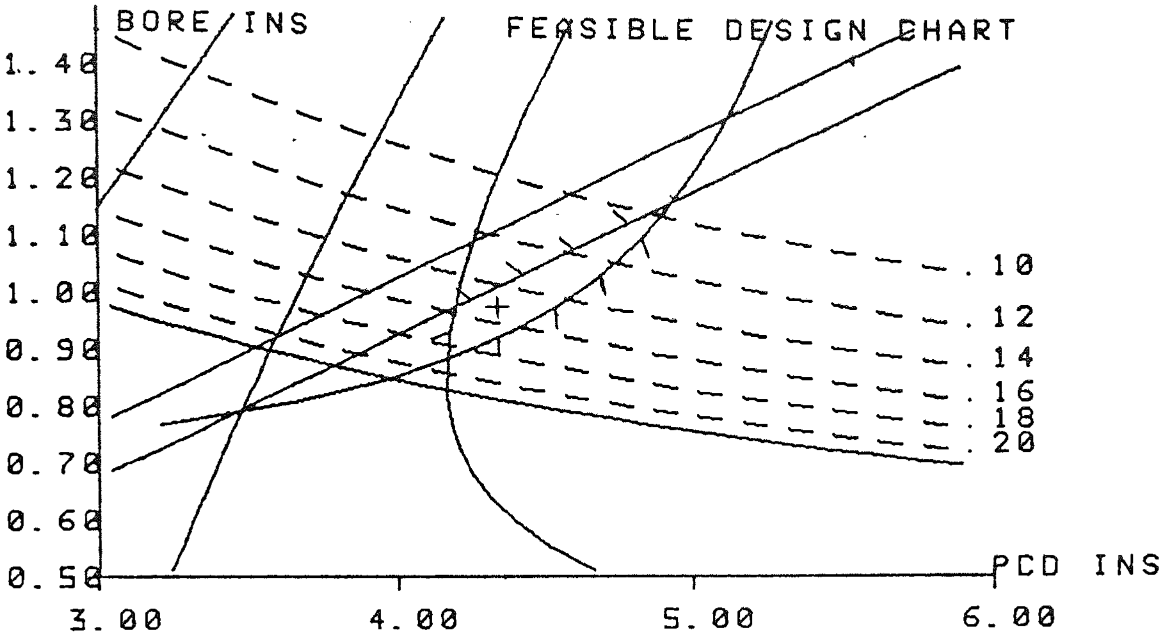
(iv) The designer should be able to see clearly which constraint is limiting his design choice. This may provoke the channelling of resources into a particular development area to push back the constraint.

These were the main benefits seen early in the project. Later in the thesis, they are compared with the benefits that actually ensued.

5.1.4. Checking the programme

As the programme described here was developed over a year before it was due to be implemented at the company, it was essential that the programme be tested to see how well it was suited for the application. Two aspects needed to be checked: was the programme accurate and effective from a technical point of view, and was the design of interaction acceptable to the prospective user.

The first of these points was investigated by "re-designing" existing pumps to see how they fared. Some of the results are shown in figs 5.3 and 5.4. These results shed some light on the company's existing design procedures by showing clearly which constraints had proved most severe in the past. The programme also showed clearly the different benefits of seven and nine piston models, (something that had not been obvious to the company before).



Actual design marked thus:- +

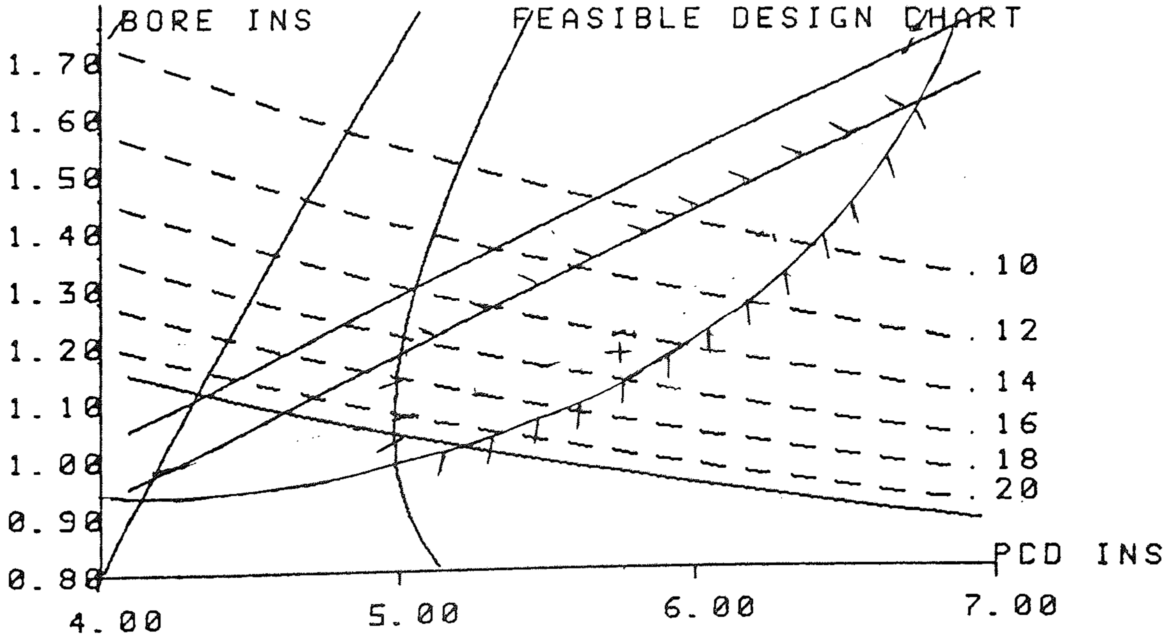
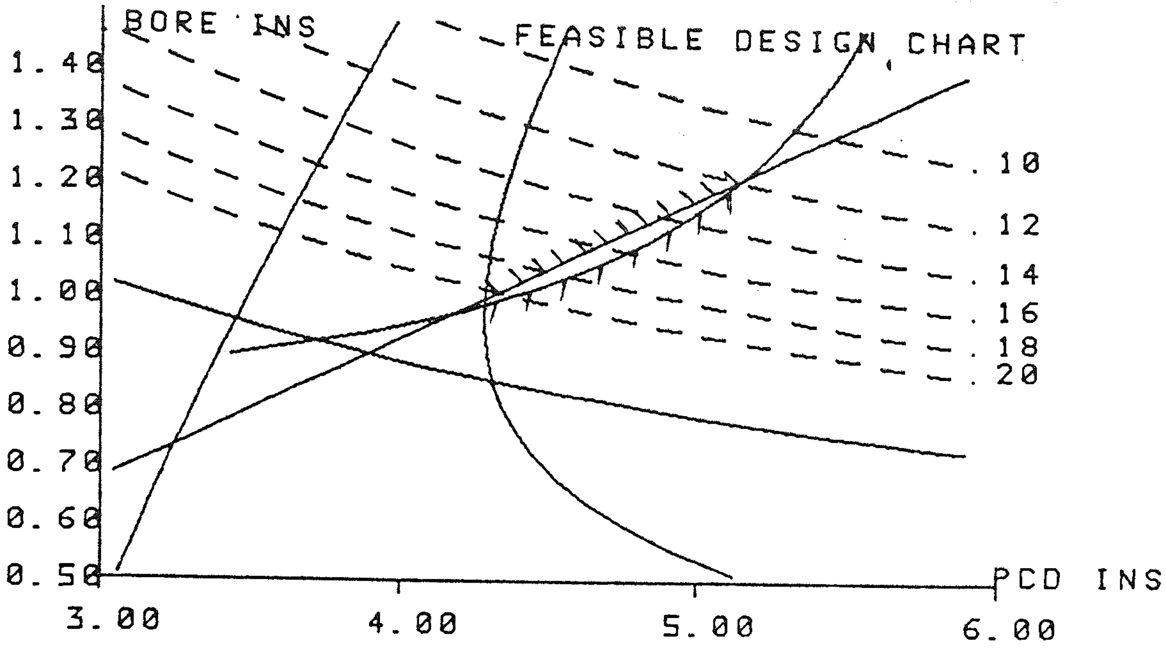


FIG. 5.3 'Re-design' of two existing models using the Design Feasibility programme

9 PISTON MODEL



7 PISTON MODEL

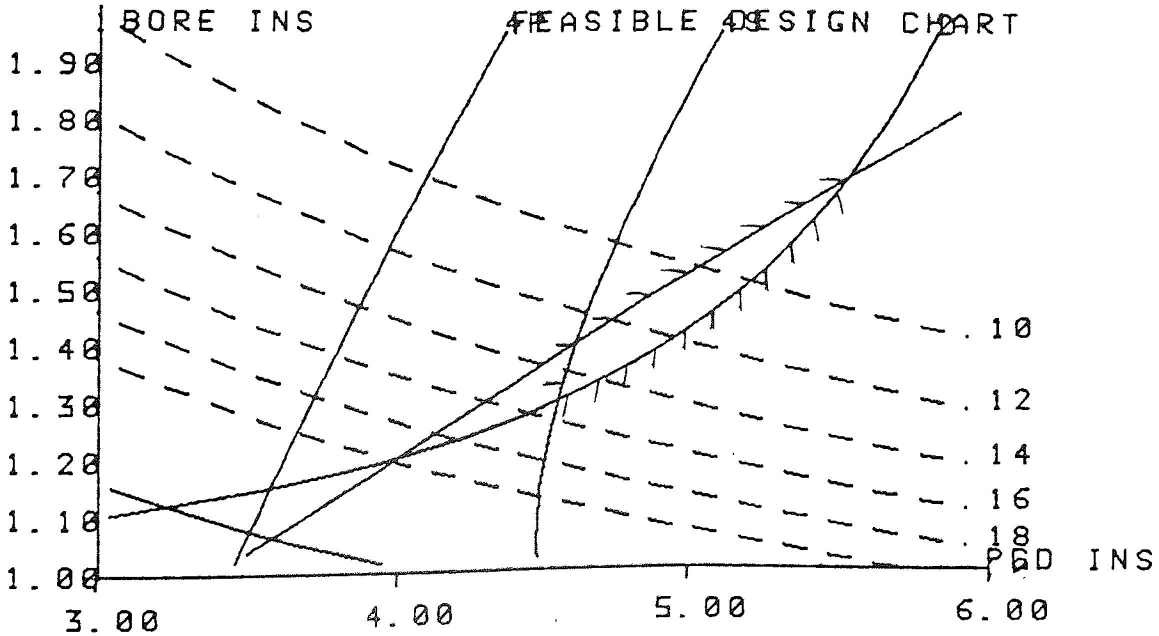


FIG. 5.4 Comparison of nine and seven piston alternatives for the same specification

On the question of acceptability to prospective users, this initial version of the programme was tested on three sample users. One was from outside the company but had a technical knowledge, the other two were engineers from the company. Several shortcomings became apparent. There was criticism of the rapid speed of output on the computer terminal and of inconsistencies in requested input. The problems were noted but correction was left until the system was implemented on the company's computer, to avoid repetition of work.

Naturally this brief check could not be a complete vindication of the programme, but the generally favourable response of the users did suggest that the philosophy and approach used were adequate.

5.1.5. Review

The feasibility programme achieved some of the objectives, both technical and human, set out in chapter 3. The computer and designer have been matched effectively to leave overall responsibility in matters of judgement with the designer. The programme results also correlate well with existing designs.

However, the feasibility study is only the first phase of the design process. By this stage, the designer has chosen one or two speculative designs which he knows are consistent. He will now wish to go on to develop a chosen design and define all of the basic dimensions so that perhaps a sketch can be drawn. After this, he may wish to predict the performance of the pump prior to draughting detailed drawings.

In chapter 2 the feasibility, preliminary and detailed phases of the design process were described. A parallel can be seen if these are now compared with the project objectives.

Feasibility	Feasibility programme
Preliminary design	Pursue a feasible design until all of the basic dimensions have been defined.
Detailed design	Detail the design sufficiently to carry out a performance analysis.

This comparison led to the conception of the three stage design system structure shown in fig 5.5. This structure will enable a design to be pursued from specification to detailed drawing. The feasibility programme just described constitutes the first stage.

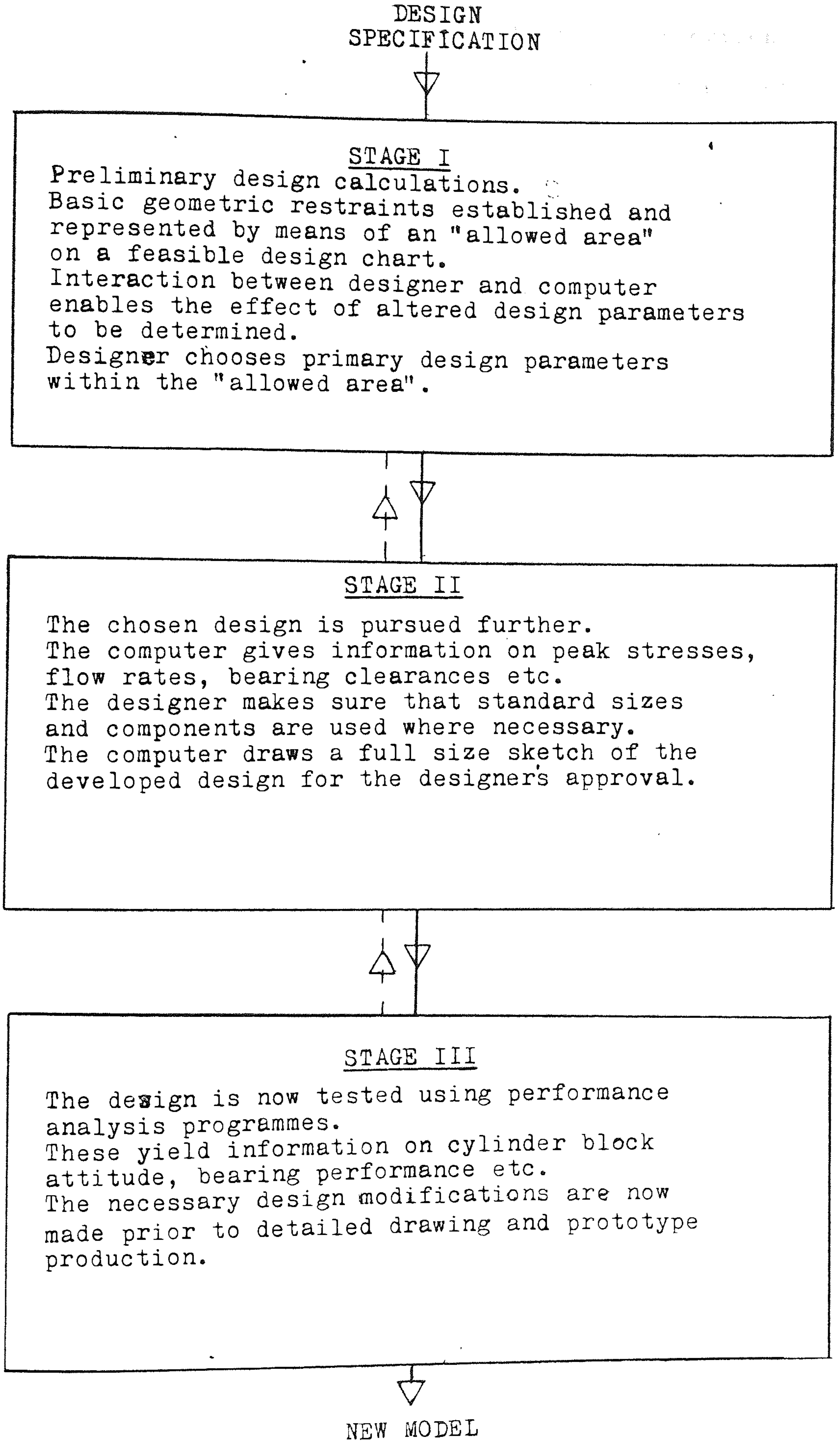
5.2. The Design Suite

5.2.1. Objective of the design programmes

As shown in figure 5.5, the objective of the design stage is to take a provisional design from the feasibility programme and develop this until all of the basic dimensions are known. At this stage the designer should have enough information to draw a scheme layout of the running gear components. However, rather than leave this task to the designer we can arrange for the computer to produce this sketch.

Using the original design procedures, the production of a scheme layout had been necessary for two reasons:-

(i) To ensure the basic geometric consistency of the design produced.



DESIGN SPECIFICATION

STAGE I

Preliminary design calculations.
Basic geometric restraints established and represented by means of an "allowed area" on a feasible design chart.
Interaction between designer and computer enables the effect of altered design parameters to be determined.
Designer chooses primary design parameters within the "allowed area".

STAGE II

The chosen design is pursued further.
The computer gives information on peak stresses, flow rates, bearing clearances etc.
The designer makes sure that standard sizes and components are used where necessary.
The computer draws a full size sketch of the developed design for the designer's approval.

STAGE III

The design is now tested using performance analysis programmes.
These yield information on cylinder block attitude, bearing performance etc.
The necessary design modifications are now made prior to detailed drawing and prototype production.

NEW MODEL

FIG. 5.5 Three stage structure of the Design System

(ii) To allow the designer to compare the different alternatives directly. (In this comparison the designer relied, to a certain extent, on whether an alternative "looked" right).

With a computer aided system, the geometric consistency can be checked internally in the software. However, the designer may still wish to see a chosen configuration drawn to get a feel for how the finished unit will look. Additionally, being able to check the design software in this way should give the designer more confidence in the system. For these reasons the scheme layout was adopted as a target for stage 2 of the design system.

5.2.2. Partial re-design of units

The design system was primarily intended for the complete design of new models. In this situation each component is designed subject to the constraints of those parts not yet designed. (The difficulty of this task led to the adoption of the synthesis approach to design as described in chapter 4).

However, improvement and uprating of existing designs also features largely in the company's work, and in this event the designer may wish to re-design only part of a unit. In these circumstances it is desirable to be able to run just that part of the design suite concerned with the component under review.

This was achieved by using a modular approach in the programming (this is described fully in the next chapter). The design suite thus consisted of discrete modules for each component of the design. When running the overall suite several modules were called in turn, and administrative sections ensured that the designer could manipulate these as he wished. For partial re-design, however, only the relevant module was used in isolation from the rest of the suite. Where necessary, additional interactive header sections were provided to allow the designer to specify the exact design situation to the computer. In this way, a suite was produced which could cope with both complete design and partial re-design.

5.2.3. The stand-alone package

The design suite produced consisted of sections concerned with cylinder block design, piston design, journal bearing design, portplate design, and a flexibility analysis package. The journal bearing package and the flexibility package were similar in that they could each be used as either a design programme or a performance programme according to the stage of design work being pursued. These two packages are now described briefly as examples of the philosophy behind the software.

(i) Bearing design package

As shown in figure 1.4 the company's design of pump uses two journal bearings to support the rotating cylinder block. There are two key aspects to be considered when designing these bearings. First the geometric design must ensure that they are compatible with the overall design. Then, a hydrodynamic analysis must be used to ensure that the bearings will perform adequately under all operating conditions. The feasibility programme ensures that the designer chooses a geometrically consistent design, but at that stage only the primary design parameters are chosen. At the design stage, the designer is asked to select bearing dimensions within specific limits calculated by the programme. In addition to geometric limits though, there are performance criteria, hence the need for a hydrodynamic analysis.

Expertise in the field of journal bearing analysis is such that it is possible to accurately predict the performance of most bearing configurations. (The Engineering Science Data Sheets [19] were used as a basis for the software in this case). All that remained was to transfer this technology into the design office and adapt it to the designer's particular needs. In this way, a tailor-made design aid was produced compatible with the overall system. A full description of this package is given by the author in ref. 20.

(ii) Flexibility analysis package

The flexibility of the cylinder block has a great effect on the performance of the unit. At the feasibility stage a rough assessment of the flexibility is made and a constraint on the design chart informs the designer.

> However, it is not possible to accurately assess the flexibility until the end of the design stage when the geometry has been fully defined. What is needed then, is a method of rapidly determining the flexibility of the design under consideration. An accurate assessment is possible using the Finite Element method, but as will be described later this is too cumbersome for use as an interactive design tool. Eventually, a modified beam analysis was derived which produced results correct to within 10%. (This method is described by the author in ref. 21). This was quite adequate for use in conjunction with the other design software.

These two examples show how, by using existing knowledge, simple, effective design packages were produced. These can be used either as stand-alone aids or interfaced with the other members of the design suite. Further details of the structure and presentation of the programmes is given in chapter 6.

5.2.4. Appraisal of the design programmes

The programmes just described formed stage 2 of the three stage design system and were intended for eventual implementation on the company's computer system. Two of the modules have been described briefly. In addition to the calculation modules, a further set was necessary for producing the running gear sketch. The whole suite is shown schematically in fig 5.6.

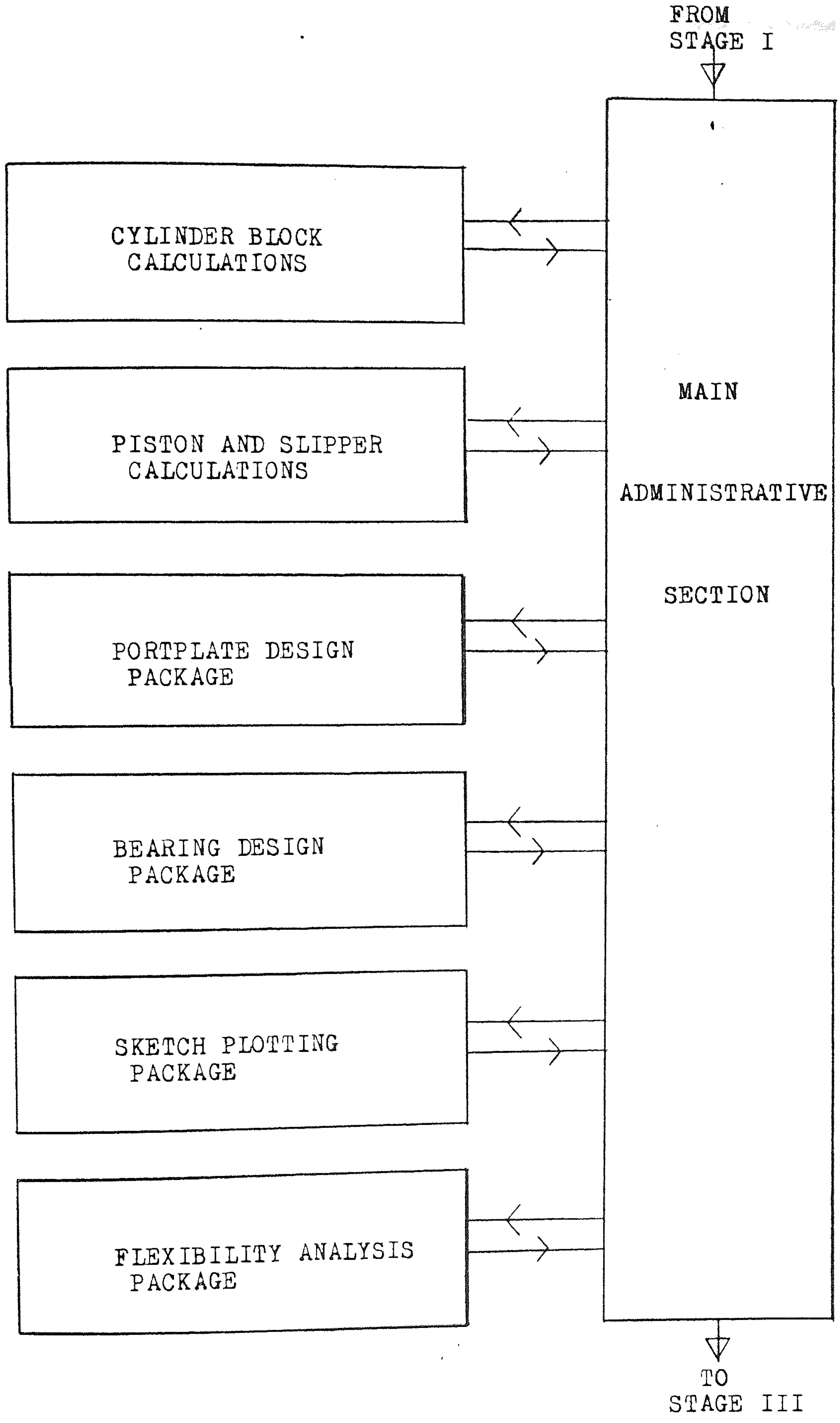


FIG. 5.6 Salient modules of the Design Stage suite

This basic suite was sufficiently complex to test the concept of design modules and set the necessary precedents for future work. Such work may consist in uprating existing modules or producing additions; company research will contribute the necessary knowledge for this.

5.3. The Performance Programme

To summarise development so far, the feasibility programme enables the designer to establish a consistent set of primary design parameters. The design suite then allows further development; each component of the pump may be designed in turn and then a complete sketch may be drawn. The design thus developed,must now be passed onto the performance analysis stage for further evaluation.

5.3.1. Aim of the programme

Following the three stage approach for the design system we now come to the third stage in which we wish to predict the performance of the chosen design. In section 5.1 we saw how this stage bears comparison with the detailed design phase of the conventional design process. Indeed, in many ways, this stage forms an extension of the design stage as well as a performance analysis.

The basic scheme layout from stage 2 is used as the input to the performance programme. Although, by this stage, most of the dimensions have already been provisionally decided, some critical tolerances and final parameters have still to be chosen. One of the objects of the programme is to show the designer the effect these tolerances have on the performance of the unit.

There is a possibility that a design produced in stage 1 and 2 may prove unsatisfactory at the performance stage, but in this event, the design system will at least have prevented the poor design from going on to the detailed drawing stage. What is more likely, however, is that the tolerances and exact dimensions will be adjusted to give adequate performance.

In order to ensure that the performance programme was an effective part of the overall system, special regard had to be given to the coupling between this programme and the other stages, and also to the interface between the programme and the designer. These tasks were particularly difficult in view of the fact that an existing analysis programme was used as the basis for the performance programme.

5.3.2. Technology transfer

In chapter 2 of this thesis one of the sources of design information suggested was academic research. This information can take many forms: personal knowledge of staff, reports and theses, or computer programmes. In this instance a useful piece of research into the behaviour of axial piston pumps by Madera [22] had resulted in the production of a pump performance programme. This programme predicted the attitude which the pump cylinder block would take on the portplate when run under specified operating conditions. By judicious use of the programme it was also possible to assess the effect of minor changes in the geometry. This was useful for tolerancing and optimisation work.

The original programme had, however, been developed in an academic environment, for the use of those immediately concerned with the research project. It was, therefore, not very useful for industrial applications. A number of steps were necessary to transfer this technology into the design office.

The interfacing between the user and the programme had to be designed to allow the user to manipulate the programme quickly, confidently and effectively. This primarily involved translation from a batch oriented system to an interactive type.

The programme had to be made compatible with the overall design system so that the design work flowed smoothly from stage 1 to stage 3 without too much manual transfer of data. This was tedious as the programme had been developed in isolation, and certainly not with a minicomputer in mind.

The programme then had to be made easier to understand so that the designers appreciated its usefulness. This, in turn, stimulated interest which eventually led to further development and improvement of the programme.

5.3.3. Assessment of the programme

As with most analysis programmes, there are assumptions and limitations in the theory of the performance programme and results have to be interpreted carefully by those who understand the fundamental mechanism. However, the programme does rapidly provide a guide as to the adequacy of the alternative designs, and the availability of the programme should allow the designer to predict the performance of a unit as soon as he has produced a rough scheme layout. Thus, as part of the overall design system it forms the compatible performance package required.

Additionally, as a pure analysis tool it allows existing designs to be assessed, for example in the investigation of failures. So in itself, it constitutes a useful design office aid.

5.4. Review of the Developed Design System

We have now discussed the three stages comprising the design system. These have been derived so as to allow the designer to pursue his work swiftly and effectively. Ample scope has been allowed for future development of any of the stages, provided that the additions can be produced in a modular form suitable for rapid interactive operation. This, then, is the main precedent that has been set for the design system.

Unfortunately not all packages will fall into this category. For instance, the Finite Element programme developed by Hooke [23] was originally too large for use on a minicomputer. Even after the size had been reduced by dividing it into smaller modules, the general form was still not compatible with the basic design system. Rather, the tool featured as a separate analysis aid for detailed investigation of specific stress or deflection problems.

This latter example suggests a third way in which new knowledge may be fed into the overall design system. The three ways we have discussed are then:-

(i) The knowledge may be the basis of new modules developed for the three stage design system;

(ii) The knowledge may provide data or parameter values for existing design modules.

(iii) The knowledge may be built into a back-up analysis programme for specific investigations.

6.0. PHILOSOPHY ADOPTED FOR STRUCTURE AND OPERATION OF PROGRAMMES

In the last chapter, a general description of the design system was given. We now go on to discuss some of the methods used to ensure that the system programmes could be effectively controlled by the designer. Some details of the interactive and graphics sections are given, and the way in which the programmes were structured to obtain a flexible, easily maintained system is described. Appendix C contains full listings of a number of interactive programme runs; salient features are referred to in this chapter.

6.1. Programme Structure

6.1.1. Programme modules

The structures of all the programmes were made modular, so that each programme consisted of a number of discrete sections. Interfacing was achieved by administrative sections. In this way, very flexible programmes were constructed. These programmes could be easily modified simply by amending that particular section under review. Indeed, sections could be replaced completely provided that the replacement had the same interface as that removed.

The general classes of sections used were as follows:-

(i) Administrative sections to organise the execution of the programme and pass control to the designer where necessary.

(ii) Data input and output sections to arrange the data so as to be compatible with the overall system conventions. These concerned communication with both the design terminal and the computer file system.

(iii) Calculation sections to perform the engineering calculations logically.

(iv) Plotting sections to display graphics on the design terminal.

Figure 6.1 shows the main sections of the feasibility programme. An unusual feature of this programme is the administrative section 'HELP'. This enables the designer to immediately re-direct control to another part of the programme. To do this he need only reply HELP to a YES/NO question.

The same modular philosophy was used for stage 2 of the system, and enabled the production of packages that could be used either as stand alone programmes or coupled into the main design suite. The bearing design package, for example, consists of a large number of sub-sections, but the whole may be used in either stand-alone or satellite mode. By using the programme in stand-alone mode the designer may analyse any bearing configuration he cares to define. Used as a satellite, the package may be called by the designer during execution of the main design programme, in order to design adequate bearings for the specific pump concerned.

A similar situation arose with the performance stage. The original performance suite consisted of four programmes which had to be run successively in order to complete a full performance analysis. This suite was already modular, but the coupling was inadequate: most of the data had to be

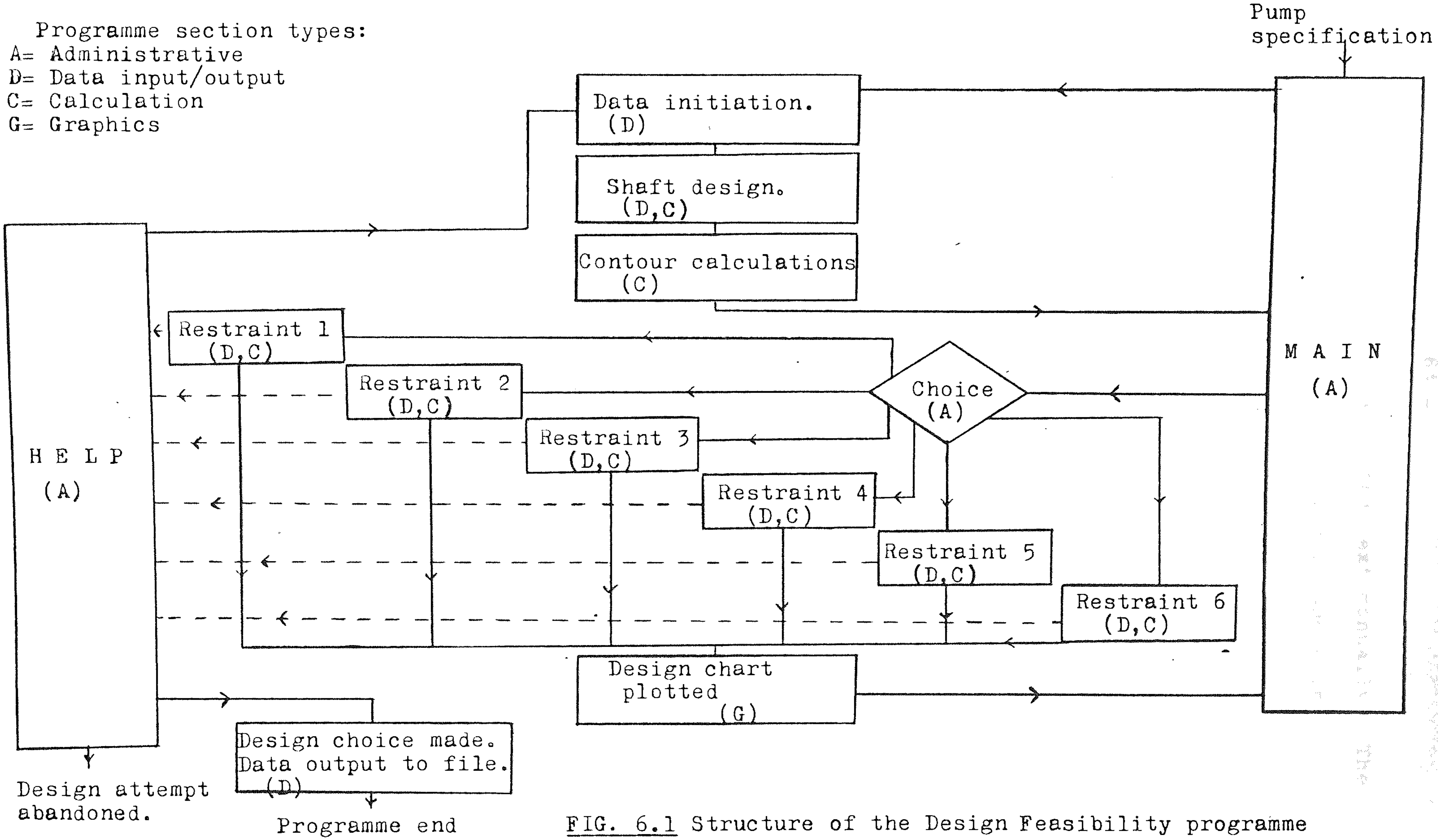


FIG. 6.1 Structure of the Design Feasibility programme

transferred from one programme to the next manually. The way in which this coupling was improved is shown in fig 6.2.

6.1.2. Programme size

If the design system programmes were to run efficiently on a multi-user minicomputer system, it was necessary to reduce the size of each programme to roughly a third or less of the computer's memory capacity. (This would allow two or three users to use the computer simultaneously). For the minicomputer envisaged this corresponded to about 15-20K. There are three ways in which budgeting in this respect can be achieved.

The first way is in the choice of programme type. It is desirable to use simple programmes or programmes that make use of pre-calculated data. The flexibility analysis package fell into the former category; the calculations were straightforward and there was no need for large arrays. The resulting programme was therefore much more suitable for minicomputer use then the finite element programme. The bearing design package, on the other hand, made use of pre-calculated data. This meant that any code and arrays necessary to the original calculations could be omitted. This again resulted in a smaller programme.

The second way in which programme size can be reduced is in the writing of the programme, once the general type has been decided. Backing store (usually disc), rather than memory, can be used for data that is not immediately necessary to the programme. Programmes can also be overlaid so as to reduce their total memory requirement. The modular

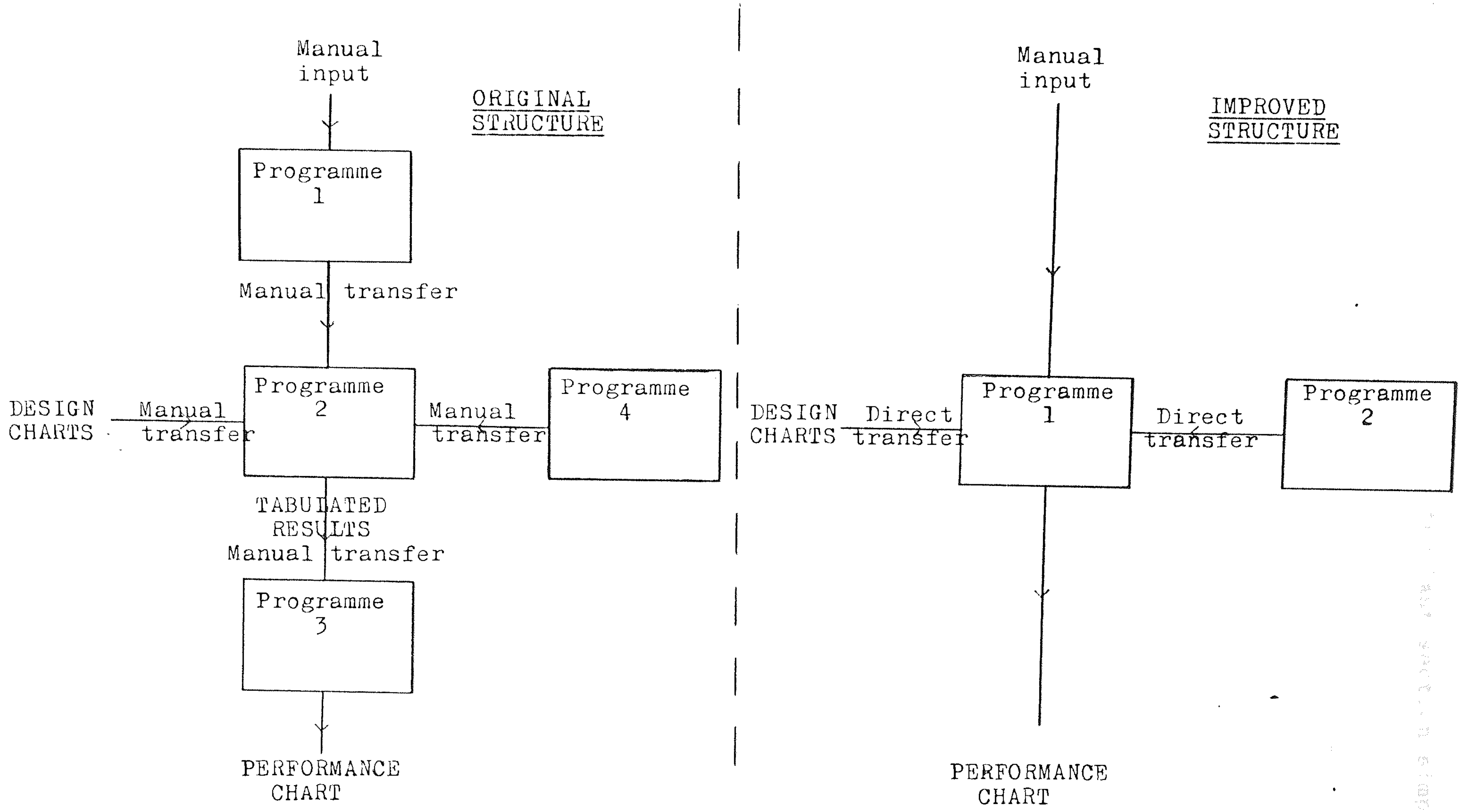


FIG. 6.2 Improvements made to the structure of the Performance Stage

programme structures discussed in the last section simplified the task of overlaying.

The final way in which programme size can be reduced consists in programme arrays and variables sharing common storage, (i.e. making use of the COMMON and EQUIVALENCE facilities in Fortran). However, this practice can tend to complicate programmes and make them more difficult for programmers to understand. This in turn can make maintenance more difficult. For this reason the practice should be used with discretion.

All of these methods were used to reduce the size of the design system programmes. The three stages were each overlaid, and the performance stage, in particular, was the subject of other structural economies. In addition to enabling the required reduction in size, some of these measures also resulted in programmes which ran faster and were, therefore, more attractive as interactive programmes.

6.1.3. Standardisation of programmes

In order to ensure that the design system was easily maintainable, it was necessary to produce software that was easy to understand. In this way the effect of staff changes was minimised. One of the main steps towards this goal was to lay down a common standard for the programmes produced. This meant that programmers then had to become familiar with only one convention rather than a number.

The seed for this standardisation was sown about a year before the minicomputer was installed when a guide to programme writing and documentation was produced. This enabled other programme writers to prepare for introduction of the computer system.

Three general maxims were laid down in this guide:

(i) The method and nature of documentation of programmes should conform to one standard, with each variable and subroutine described and the theory explained.

(ii) The programme listings should be liberally documented with comments which should describe clearly the purpose of each section of code.

(iii) Variable names should conform to the common standard, the names should be global (i.e. consistent throughout the programme) and wherever possible transfer between segments should be by named common blocks.

These standards were necessary for ease of maintenance. Additionally in order to ensure that packages produced blended together in the design system, certain conventions on input/output had to be laid down, but by and large these were less rigid. Some of these are described in the next section.

6.2. Designer-Computer Interaction

6.2.1. Dialogue type

In chapter 4 we decided that the most suitable type of computer aided design system would be computer initiated but designer controlled. This led to the adoption and development of an interactive computer aided design system. The programming language adopted was FORTRAN. In order to incorporate an effective computer initiated dialogue into this framework it was necessary to anticipate at the programme writing stage, how the system would be used and exactly what would be required of it. This then enabled the appropriate designer-design system interaction to be programmed into the software.

Martin [24] reviewed a large number of man-computer dialogue types. Some of these are summarised in figure 6.3.

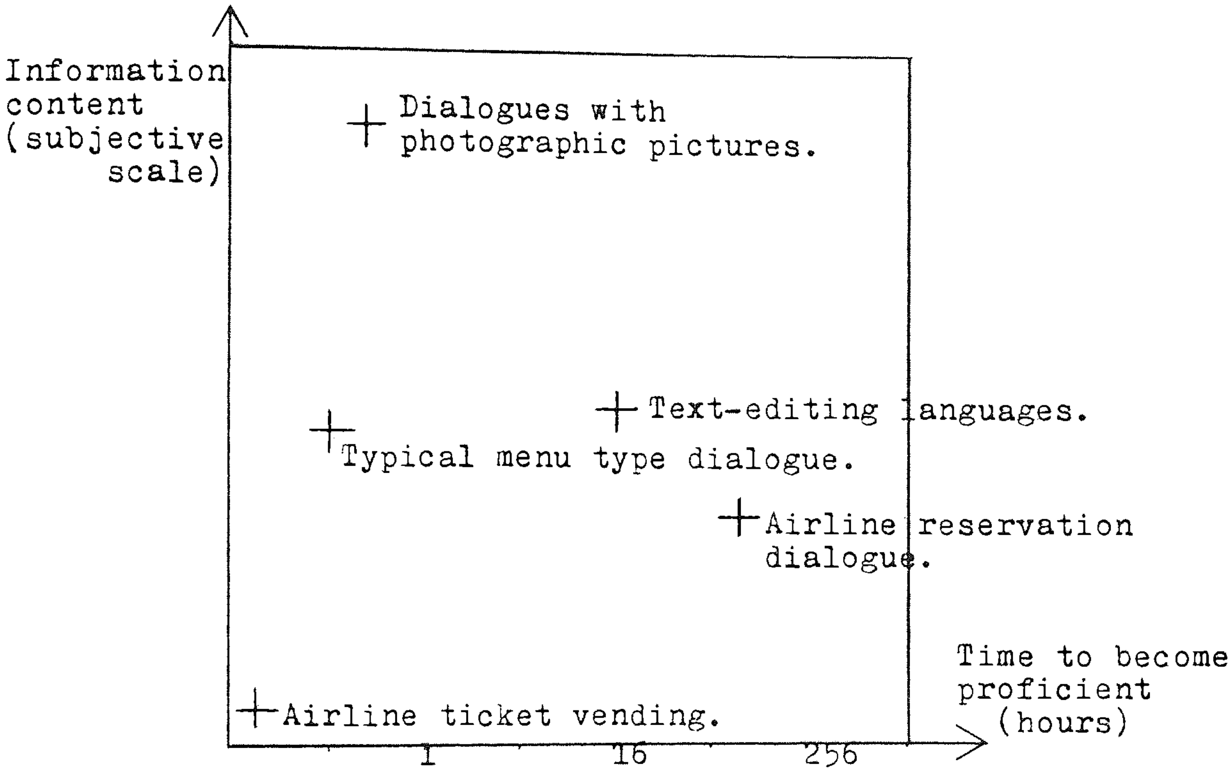


FIG. 6.3 Martin's comparison of dialogue types

The dialogue type used in this project consisted in the computer presenting questions or prompts to the designer, who, in turn, could make a limited number of responses. This falls into the menu category of dialogues. This choice was made because menus can be incorporated cheaply and simply into almost any computer system, regardless of hardware or software differences. Nonetheless, provided care is taken during the programming, they allow production of a dialogue flexible enough for most situations.

If we exclude the case of numerical data input for the moment, two types of designer prompt were used:

(i) The type requiring a 'yes' or 'no' response.

(ii) The type requiring selection of an option from a list.

To make the simple yes/no prompt more flexible, a third option was offered as an acceptable response in some programmes as shown below. This was the HELP option which allowed the designer to immediately transfer control back to a selected part of the programme.

```
WOULD YOU LIKE TO KNOW THE TORQUE? YES
PUMP TORQUE IS 353.7 LB. FT. IS THERE ANY EXTRA
TORQUE? HELP
PLEASE ENTER ONE OF THE FOLLOWING:-
1 = I WISH TO ABANDON THE PROGRAMME
2 = I WISH TO RE-COMMENCE THE PROGRAMME
3 = I WISH TO BEGIN STAGE 2 OF THE DESIGN
4 = I WISH TO ALTER THE DESIGN CHART SIZE
CHOICE? 1
PROGRAMME ABANDONED.
```

(Underlining denotes a response from the user)

The option list was more versatile and allowed the designer to select one of a number of alternative courses. This method was used for the selection of design restraints in the feasibility programme.

```
WHICH DESIGN RESTRAINT WOULD YOU LIKE TO PLOT?
1 = SLIPPER SEPARATION RESTRAINT
2 = CYLINDER SLOT HEAD LOSS RESTRAINT
3 = NECK STRESS RESTRAINT
4 = JOURNAL GEOMETRY RESTRAINTS
```

```
5 = BORE AND SLOT SEPARATION RESTRAINTS
6 = BLOCK INSIDE WALL THICKNESS RESTRAINT
999 = HELP!
CHOICE? 1
SLIPPER SEPARATION RESTRAINT ***
```

The success of this simple type of dialogue in the design system can be explained by the simplicity of the programme flow charts. Because the objectives and alternatives were planned systematically, control of the system was straightforward.

Returning now to the case of numerical input, the main aim here, was to ensure that the designer had the freedom to standardise values calculated by the computer. At the end of many calculations, the designer was given the chance to choose a standard size for the dimension concerned; this was then used as a basis for further calculations by the computer.

```
CALCULATION OF MINIMUM SHAFT DIAMETER ***
PLEASE ENTER THE FOLLOWING:-
APPROXIMATE STRESS CONCENTRATION FACTOR? 1.5
DESIRED LOAD FACTOR? 2.0
STRESS CONCENTRATION FACTOR = 1.5
DESIRED LOAD FACTOR = 2.0
IS THIS CORRECT? YES
MINIMUM SHAFT DIAMETER = 1.218 INS
DO YOU WISH TO CHOOSE A SHAFT? YES
PLEASE ENTER THE FOLLOWING:-
CHOSEN SHAFT DIAMETER INS? 1.25
STRESS CONCENTRATION FACTOR FOR THIS SHAFT? 1.5
```

```
THE LOAD FACTOR FOR THIS SHAFT IS 2.158

ARE YOU HAPPY WITH THIS SHAFT?  YES
```

This same method was also used to enable the designer to evaluate the effects of tolerances on critical dimensions.

```
PORT PLATE GEOMETRY ***

OUTER LAND O/R = 1.982

OUTER LAND I/R = 1.840

INNER LAND O/R = 1.660

INNER LAND I/R = 1.532

PORT PLATE I/R = 1.185

DO YOU WISH TO CHOOSE THE LAND RADII?  YES

OUTER LAND O/R?  1.983

OUTER LAND I/R? 1.841

INNER LAND O/R?  1.659

INNER LAND I/R?  1.531

RATIO OF INNER:OUTER LAND WIDTH = 0.902

BALANCE FACTOR = 2.040

ARE YOU HAPPY WITH THESE VALUES?  YES
```

For all the programmes the loops were designed so that the user could quickly re-run sections of the system with modified parameters. In the bearing design section for example, the designer could opt to alter the bearing diameter slightly, or change oil, and re-analyse the configuration before moving onto the next design region.

```
DO YOU WISH TO CALL THE BEARING DESIGN PACKAGE?  YES

PLEASE CHOOSE AN OIL FROM THE LIST BELOW:-

1 = TELLUS-15

2 = TELLUS-27
```

```
3 = TELLUS-41

4 = TELLUS-72

CHOICE? 1

PLEASE SELECT A BEARING DIAMETER? 2.25

***BEARING CALCULATIONS PROCEEDING***
```

(Bearing chart displayed after a short delay)

```
DO YOU WISH TO ALTER THE DIAMETER OR CHANGE OIL? YES

PLEASE CHOOSE AN OIL FROM THE LIST BELOW:-

1 = TELLUS-15

2 = TELLUS-27 ....
```

As stated in section 6.1, by keeping the programme simple in operation, the response time was kept short so that normally the designer was not kept waiting by the computer. In some cases delays were unavoidable, and in this situation, as shown above, a message was written out to the terminal to warn the designer of the impending delay.

6.2.2. User instruction

A second aspect of designer-design system interaction concerns the amount of advice and instruction given the designer and how this is done. In addition to the production of programme documentation as described briefly in section 6.1.3, and intended for programme writers, the design system was documented at two further levels. These two levels fell into the category of user guides and described: the general layout of the computer aided design system, how to use each of the programmes, and also briefly the theory and limitations of the programmes. (Further details are given in part III of the thesis). These guides were designed so that they could be used for reference during an interactive design session. In this way the amount of instruction which it was necessary to build into the system was minimised.

Efforts were made, nonetheless, to make the programmes self-explanatory once they had been initiated. Error-proofing reduced the possibility of the designer making serious operating errors. Here a trade-off was made between a comprehensively error-proofed system (with numerous double checks) which would have been tedious to use, and a more straightforward system less capable of handling all user errors. In fact this compromise resulted in the early system programmes (e.g. the feasibility stage) being more comprehensively error-proofed than the later ones. This was done on the assumption that users would become more experienced and confident with the system as they progressed through the stages.

All of the programmes had a basic level of error-proofing. Prompts were repeated if the wrong type of response was made, for instance, if a number was entered in response to a yes/no question. All numbers were accepted individually in free format, and adequate facility was arranged for repetition of loops so that mistakes could be altered. Some of these points are demonstrated below.

```
PLEASE TYPE THE FOLLOWING:

NUMBER OF PISTONS = 9

FLOW CAPACITY CIR = 5.5

PUMP SPEED RPM = 2500

OPERATING PRESSURE PSI = 50000

BOOST PRESSURE PSI = 150
```

```
NO. OF PISTONS =  9

FLOW CAPACITY =  5.5

PUMP SPEED =  2500

OPERATING PRESSURE = 50000

BOOST PRESSURE =  150

IS THIS CORRECT?  MO

                ?  NO

PLEASE TYPE THE FOLLOWING

NUMBER OF PISTONS =  9

FLOW CAPACITY CIR =  5.5

PUMP SPEED RPM =  2500

OPERATING PRESSURE PSI =  5000

BOOST PRESSURE PSI =  150

NO. OF PISTONS = 9

FLOW CAPACITY =  5.5 .........
```

Throughout the design runs explanatory messages were frequently displayed to inform the designer of the computers progress.

Many of these features are shown clearly in the full programme run listings in appendix C. This self-teaching style was intended to motivate the user to become more familiar with the system.

6.2.3. Programme coupling

Programme coupling was an important feature of the interaction of the system. We have already described how the programmes could be used either as part of the overall design system or as stand-alone packages. In either case, the administration was arranged so that the programme could be initiated using a single command and thereafter control was achieved through the dialogue. The computer arranged for the initiation of sub-programmes relevant to a particular run.

The transfer of data between programmes was the second aspect of coupling considered. The method adopted entailed the computer reading from file that data previously defined by the designer, however, the designer was offered the option of amending this as required. In this way the tedium of re-entering large quantities of data was avoided without loss of flexibility. Each data item was displayed in turn followed by a "?" prompt. If the designer was content with the value he typed 'YES', if not he typed 'NO' followed by the new value.

```
THE DESIGN YOU HAVE CHOSEN FROM STAGE 1 IS:

PISTON NUMBER =  9

PISTON PCD (INS) =  3.5?   YES

PISTON BORE (INS) =  0.7?  NO

NEW VALUE?  0.75

SWASH ANGLE =  15.0?  YES
```

This type of programme coupling had to be developed in conjunction with a unified data structure. The data structure adopted is described in chapter 7.

6.3. Type of Graphics used

6.3.1. Philosophy adopted

Graphic displays were used a great deal, in the design system, as a means of conveying large quantities of data to the designer. A wide variety of types were used: the type and corresponding philosophy depended on the application. Some conventions, however, were applied universally throughout the system.

Two dimensional displays were used throughout to avoid optical illusions or other problems of interpretation, however, much use was made of contours of various types to represent a third dimension. In situations where it was desirable to manipulate four parameters individually, then a display was drawn for one particular value of the fourth parameter and to assess the effect of this parameter, it was necessary to re-draw the sketch with this value modified. This situation is shown clearly in fig 5.4 where the four parameters are piston bore, piston PCD, swash angle and piston number.

This method was only made possible by the conversational nature of the graphical interaction. The displays were produced immediately after they had been defined. In the case of the feasible design chart, the display could be re-plotted very rapidly with modified parameters. The designer could also magnify the scale so as to display only the particular region of interest.

Two further conventions can be seen with reference to this design chart: that of displaying actual rather than dimensionless quantities, and that of displaying on the axes parameters for which there might be preferred values. In effect, by these means we are ensuring that the designer has a feel for the design, and that he can easily exercise his discretion in choosing standard sizes, for example for the piston bore.

A final feature of the graphics was the ease with which hard copies could be initiated. By replying "PLOT" to the question "DO YOU WISH TO REPEAT THE DISPLAY ?" the designer initiated the preparation of a hard copy. After he had selected a scale size for this copy he could proceed in the usual manner through the remainder of the design run. At the end of his design session, after he had logged out from the terminal, all of the hard copies which he had initiated would be produced on the plotter.

6.3.2. Parameters displayed

The exact form of a particular design chart was decided on two criteria: first, that the chart should be both useful and clear to the designer, and secondly, that the computing effort required to produce a particular type of chart should not result in long delays before presentation. The need for rapid response times was discussed earlier, so we will now consider only the need to produce easily digestable displays for the designer.

The benefit which computer produced charts have over those presented in manuals or drawn up by hand, is the rapidity with which they can be modified to represent altered conditions. This suggests immediately that we are going to be able to discard the generalised charts which must cater for a very wide range of parameters (usually reduced to dimensionless groups), and concentrate our attention towards tailor-made charts devised for the specific task in hand.

For instance, let us consider the problem of journal bearing analysis. In the general situation there are a number of parameters to be chosen: length, diameter, diametral clearance and oil type. The critical performance criterion might be film thickness, temperature, or stability. Any general bearing design chart must, therefore, be fairly elaborate, especially if we are also to represent the effect of varying load and speed on the chart. However, if we now consider the specific application of a bearing for either end of an axial piston pump, we have a much better defined problem. Values must be chosen for one or two parameters to ensure adequate performance under well-specified conditions. These conditions are defined directly by the specification of the pump. What is more, the parameters to be chosen must fall within limits governed by the geometry of the unit, for instance, the diameter must be within a fairly small range.

With these points in mind, the first bearing design chart (fig 6.4) was devised. Although this went some of the way towards our aims, the chart became difficult to produce and use because of the numerous families of curves displayed. Also, the average bearing pressure, although a useful parameter, could not be altered independently by the designer, and according to the philosophy adopted, should not therefore have been plotted on an axis.

These problems were overcome with the second bearing design chart (fig 6.5). In this case the chart is produced for a specific oil, a chosen diameter, and specified operating conditions. The two axes correspond to parameters which the designer is free to choose, and the two sets of curves represent the most salient performance criteria - film thickness and maximum temperature. Using this kind of chart the designer can quickly assess the adequacy of a particular arrangement and if he is dissatisfied, he knows that for these operating conditions, his only alternatives are slight changes of diameter within the limited range, or a change of oil.

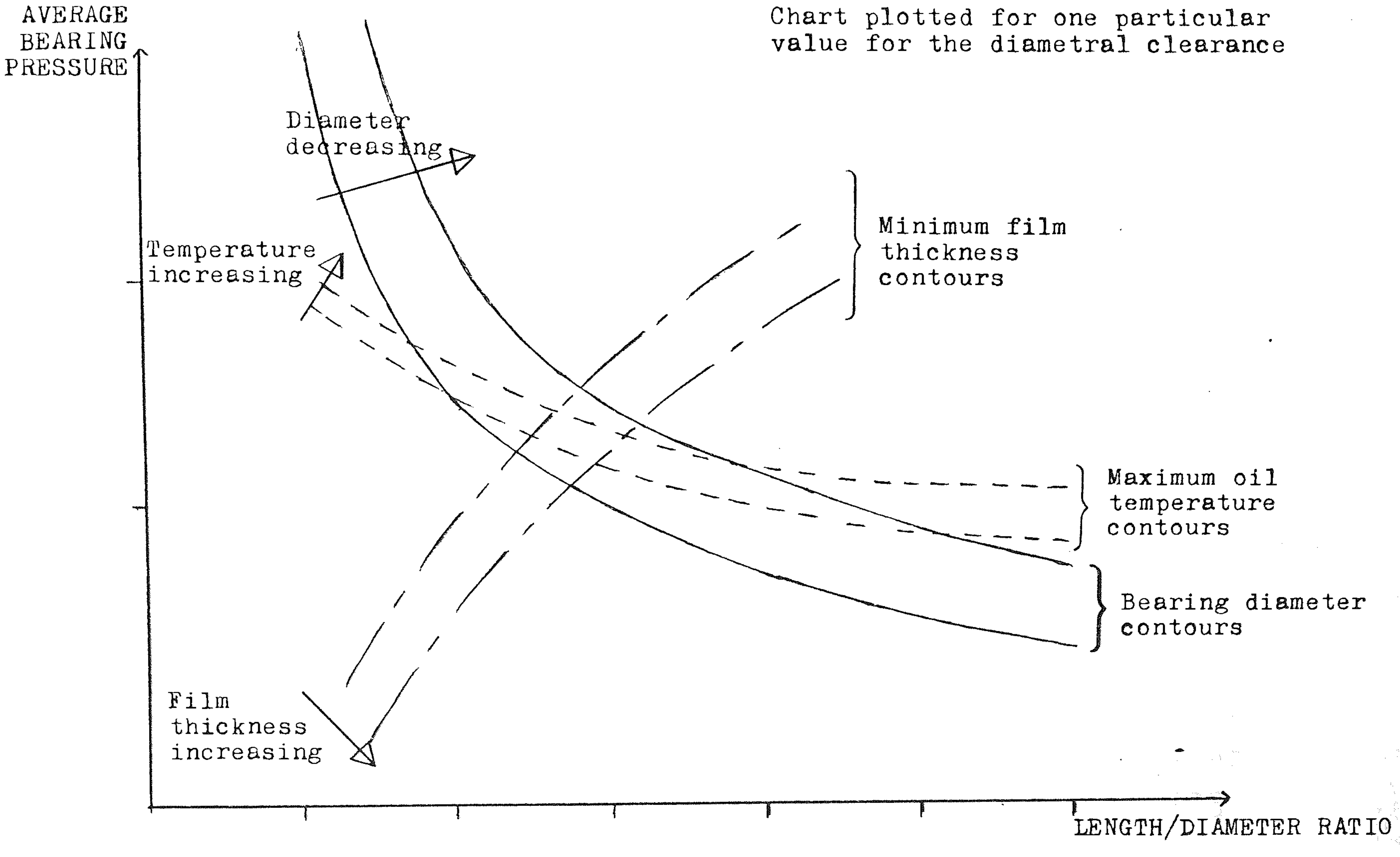


FIG. 6.4 First type of Bearing Design Chart devised

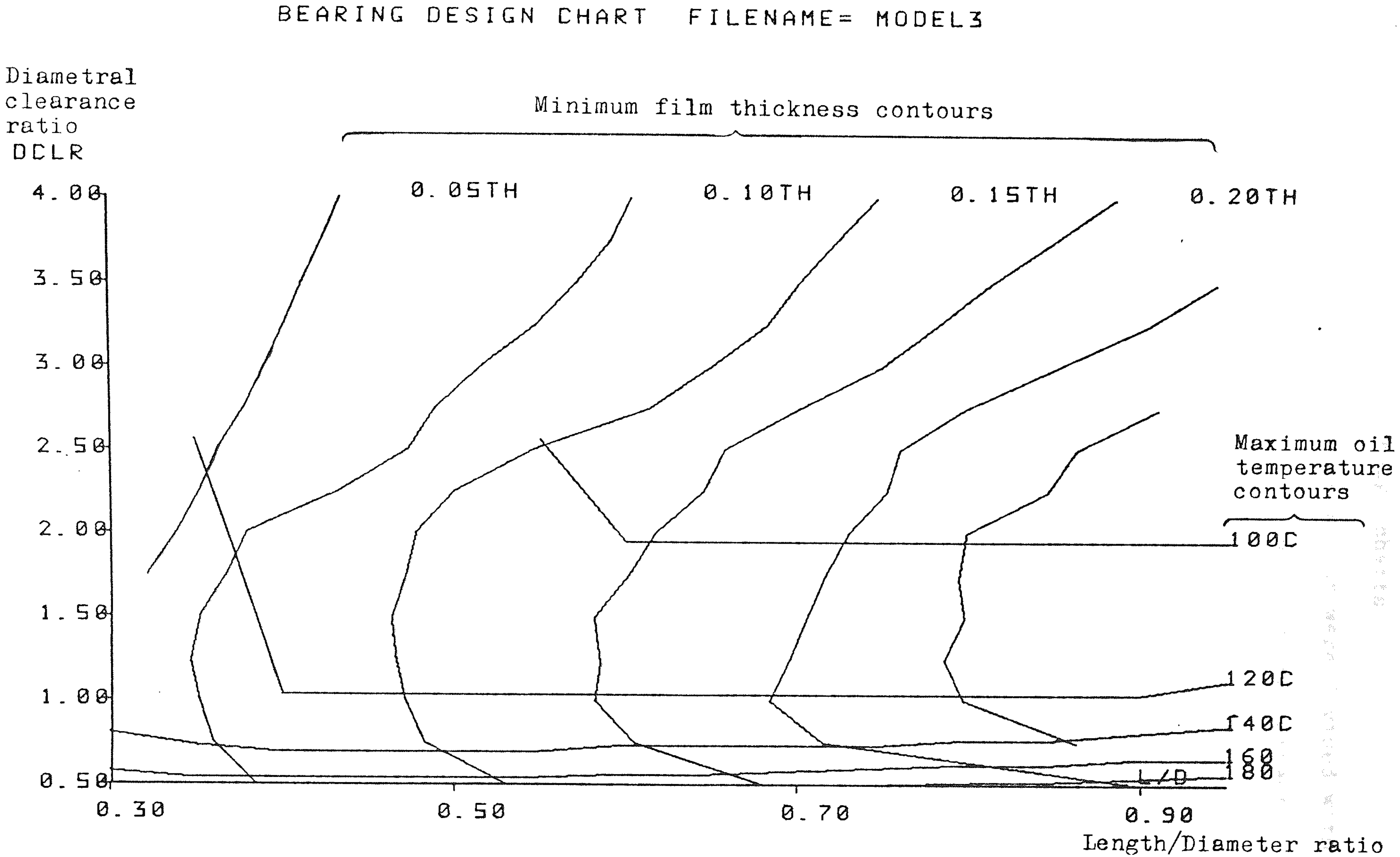


FIG. 6.5 Final type of Bearing Design Chart devised

6.3.3. Versatility of the design charts

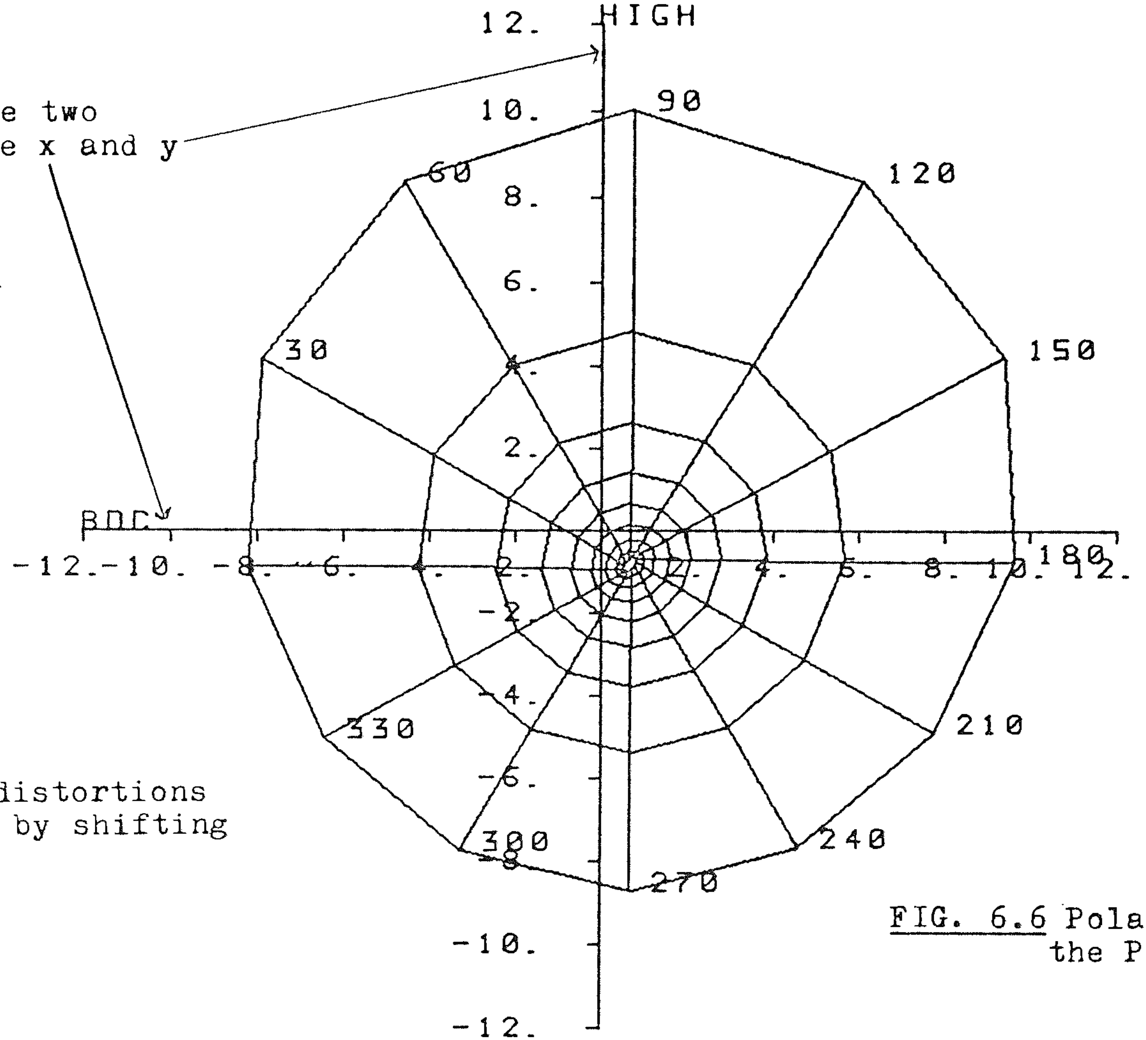
The design charts described so far were devised with one primary aim in mind. However, by choosing the correct format, the charts were made very versatile. One example has been already described in chapter 5 where the benefits of the feasible design chart were discussed. A similar sort of versatility ensued from the formats of the bearing design and performance analysis charts.

The bearing design chart predicts the behaviour of a cylindrical bearing with a perfectly aligned journal. This situation might at first seem hypothetical but fortunately because of the format of the chart the designer can quickly assess the effects that deviations have on the behaviour of the bearing. For instance, the effect of misalignment can be estimated by modifying the diametral clearance of the bearing by the amount of misalignment. Distortion, on the other hand, can be considered by modifying the actual film thicknesses predicted. Both of these modifications can be made in seconds simply by altering the annotation on the graphs.

Similarly with the polar plots produced by the performance programme (fig 6.6), the basic chart indicates the attitude of the cylinder block on the portplate for given operating conditions. The effect of the two journal bearings being misaligned relative to each other can be immediately seen, but in addition to this, the effect of casing distortions can also be assessed by shifting the axes in the appropriate directions.

These two examples show the degree of versatility

```
****POLAR PLOT****      ROTN CLOCKWISE   FILENAME= DCCHK
```



Misalignment of the two end bearings in the x and y directions.

Operating point on the chart defined by this misalignment.

Effect of casing distortions etc. accommadated by shifting the axes.

FIG. 6.6 Polar plot produced by the Performancé Programme

```
TOP PORT= 5000.0   BOTTOM PORT=  500.0   SWASH=   15.0
SPEED= 3500.0BEARING VIS=   0.0000034793PAD VIS=   0.0000034793
```

obtainable from the various design charts.

This completes a discussion of the philosophy behind some of the programmes, and a summary of the precedents which have been set for future development of the design system. These precedents have arisen mainly out of a consideration of the benefits and drawbacks of a minicomputer system, and a desire to produce a system which conforms most closely to the designer's needs. The standards set should not inhibit future programme writers, but rather ensure that the uniformity and flexibility of the system is maintained.

7.0. ADOPTED DATA STRUCTURE

In previous chapters we have mentioned the need for efficient coupling between programmes and data sources in an effective design system. In this chapter we discuss the development of the data structure finally adopted.

7.1. Need for a data structure

7.1.1. Requirements

The data required by design programmes can be divided into two categories. The first category is the primary data usually supplied by the designer in the form of decisions. The second category consists of reference data which the programme uses in design calculations. There are numerous types of reference data, for instance material properties, design parameters and pre-calculated data tables. Also, once a designer has made a decision, then that decision falls into the category of reference data, even though he may wish to modify his decision later.

If the design programmes were to run efficiently it was necessary to ensure that all this information was stored by the computer and readily available. As there were a number of design programmes all with different data requirements, it was also necessary to devise a method whereby all programmes had rapid access to all data types.

The main objective then was to devise a method of interfacing of sufficient complexity to satisfy these requirements, and allow for future expansion and modification.

7.1.2. Alternatives

The alternatives available for data transfer (excluding manual methods which are time-consuming and laborious) range from direct coupling between design packages to elaborate data base systems. We wish to use the simplest method that will satisfy the requirements stated.

The simplest alternative is to arrange for the programmes to interface directly with one another. However, this makes permanent storage of large quantities of data impractical, as the data has to be stored within individual programmes, thus increasing programme sizes. Data updating is also difficult as it necessitates programme editing for each alteration. Finally this method also leads to duplication of data for each programme. For these reasons the direct coupling alternative was rejected.

Simple sequential files are the next simplest approach. In this case the data is stored outside the programmes, often on disc, but can be obtained by any programme in a sequential order. It is possible to devise such systems to operate on any computer type. There are, however, two disadvantages. If simple sequential files are used it is necessary to have one file for each job, e.g. one for communication between programmes A and B, one for between B and C, etc., along with a file for each reference source. This leads to complicated systems which are difficult to use and maintain. Also, much data is duplicated resulting in more storage space being used and problems in ensuring authenticity of the data.

It is only a small step from a sequential file system to a simple data structure; the differences are more of convention than anything else, but the benefits are great. The idea is to have one set of files containing all the different types of information. Each category of information is stored in a different file, and no information is duplicated. Each data item has a specific location within a specific file so that it can be found very quickly by any programme. At first sight, this method looks inflexible, but provided that care is taken initially when the file types and locations are allocated, then an effective system can be produced. With this method, there is no limit to the number of programmes that may access the information and therefore expansion of the design system is made simple. (This was proven by the development of the information retrieval system described later in this chapter). Also, programming becomes more straightforward and programmes more easy to understand as they all conform to the same data structure.

The structured data system was that adopted for the design system. The first step in devising such a system was to decide what different types of information would have to be stored. This is done in the next section.

7.1.3. Extent of the data structure

Before embarking on the development of a structured file system, it is important to consider what the short term, medium term and long term plans for the system are. In this way, it is possible not only to plan an adequate data structure with enough scope for future development, but also to arrange that implementation of the plans is in the correct order. The design system devised for the company was a new venture and it was therefore sensible to start with a modest data structure which could be improved and expanded later. For this reason, data on material costs and suppliers, for example, was not included and only information that was directly relevant to the design system was incorporated. Essentially, the following had to be stored on file:

(i) All of the design packages had to be stored so that the user might immediately run any part of the design system.

(ii) The geometry and design parameters of a number of pumps had to be stored in such a way that the design programmes could reference any parameter of any pump. Similarly, when new models were being designed using the design system, then the appropriate decisions and dimensions had to be stored.

(iii) The properties of oils and metals had to be stored so that a design programme could reference them directly rather than have to request them from the terminal.

(iv) Accommodation had to be available for the additional data files that were peculiar to individual programmes. For instance, pre-calculated data was required by both the bearing design package and the performance programme.

(v) Finally a number of text files had to be included as reference material for both designers and programmers.

With this minimum of information available, the design system would be practicable. A data structure containing this information would be able to support the design programmes described in the previous chapters.

7.2. Structure Devised

7.2.1. Physical feasibility

The design system devised was intended for implementation on a minicomputer. With this type of machine the physical feasibility of a given data structure is dependent on having enough disc space to house all of the data. The most efficient arrangement for a design system would be to have all of the design data on one disc. It would then be possible to load the system into the computer very quickly whenever anyone wished to do any design work.

The disc size for the computer that was envisaged is 1200K. The total size of the design programmes (excluding the finite element programme) was less than 200K. This left 1000K of disc space for data files. Now, assuming that an average data file would be 2.5K (approximately 1200 values) then there would be room for 400 data files. This was considered quite adequate, and therefore this proposed data structure was feasible.

The 200K allocated to programmes only accounted for the running version of the programmes (not the source or object versions produced during programme development). Therefore it was also necessary to ensure that when the time came, (i.e. when the design disc became too full), it would be possible to do the necessary development on a separate disc, leaving the design system disc only for programme running. This arrangement also proved feasible.

Finally, as suggested above, the finite element programme had to be considered as a separate case. Although the size had been reduced considerably, it still could not be regarded as an interactive design programme (see chapter 5). For this reason it was decided that separate arrangements would have to be made for running the finite element programme in isolation from the main design suite; this programme was therefore allocated a separate disc.

7.2.2. Structure of the file system

The structure of the file system developed is shown in fig 7.1. The design programmes all operate off the simple framework of files. The three main categories of files are pump design files, material property files and miscellaneous data files. These categories cover most of the requirements of the data structure. The different categories will now be described.

(i) Pump design file

This is the file which contains details of the geometry of the design in question. When a design is commenced, a pump design file is automatically opened and the design produced during the course of the run is written out to this design file. Thereafter, design work can be continued on this file by specifying the file name in the appropriate programme runs. Naturally, each design has its own unique name and file, the name being that specified by the designer at the start of the first design run. Each file is split into 10 blocks of 128 values as shown in fig 7.2. Each block contains the information on one aspect of the pump. Thus, block 2 contains details of the cylinder block

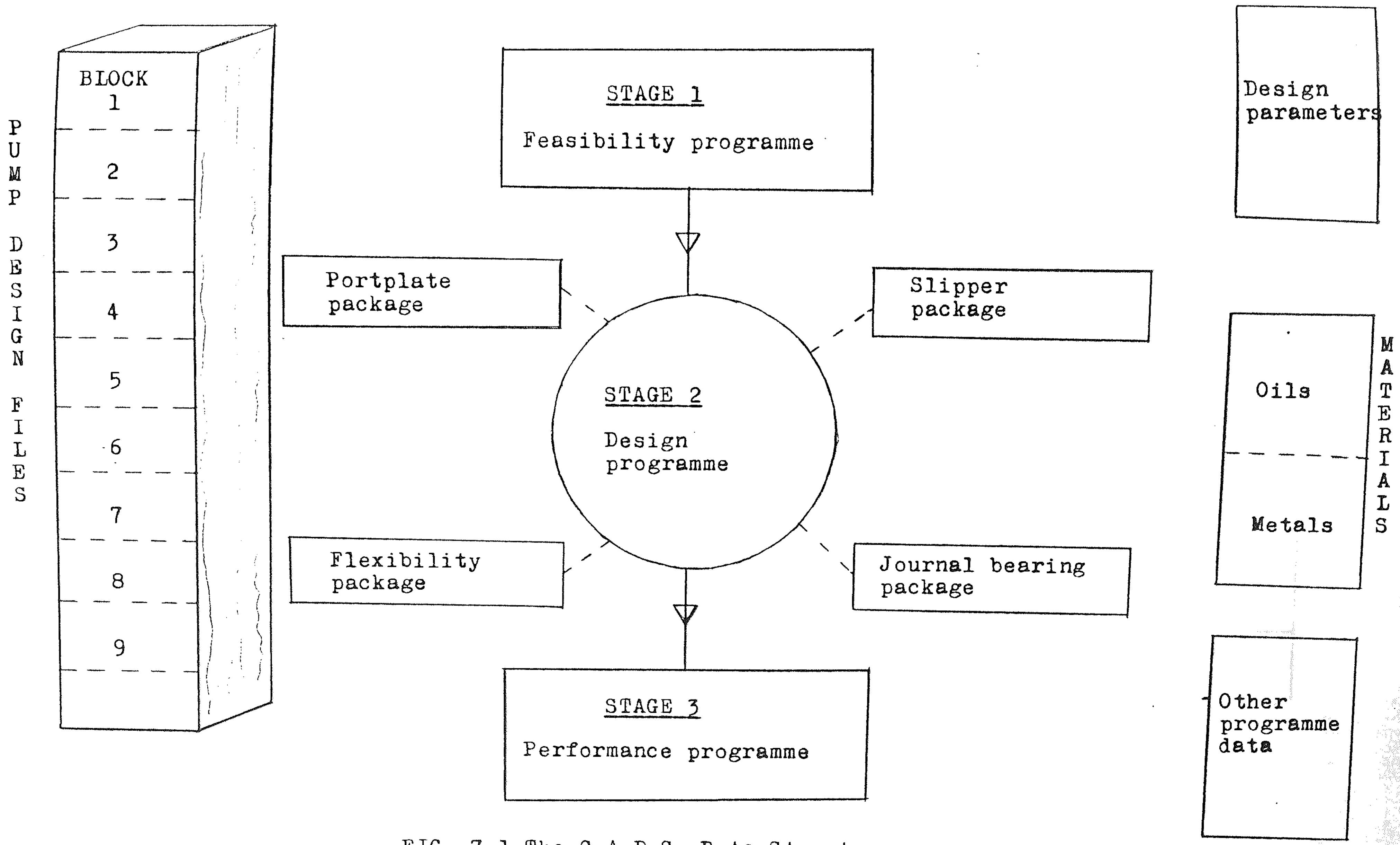


FIG. 7.1 The C.A.D.S. Data Structure

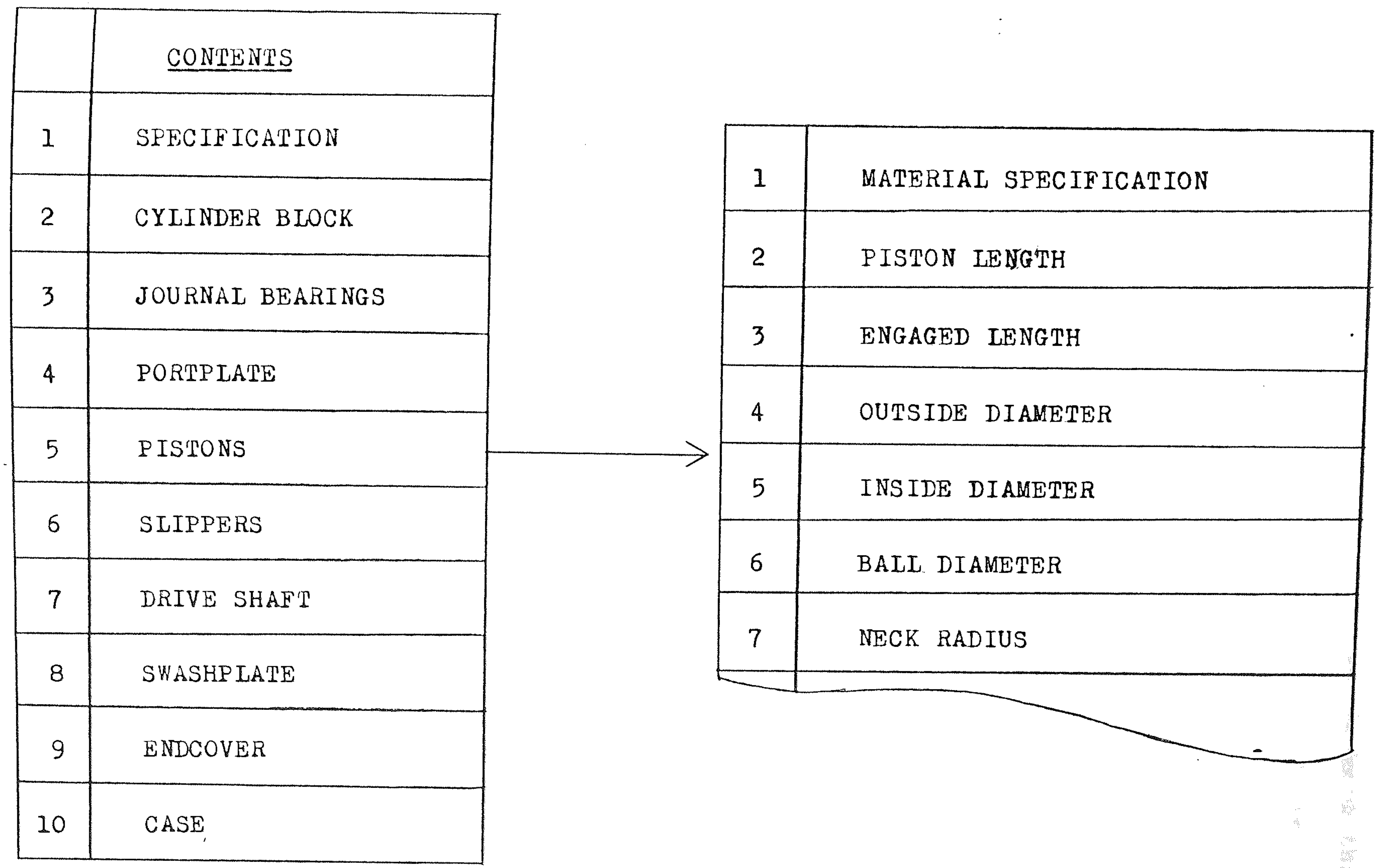


FIG. 7.2 Structure of the pump design files

and block 5 details of the pistons. (Incidentally, these blocks correspond to physical blocks on the disc, a factor which contributes to effective file access for the programmes).

Now, if we consider, for instance, block 5 more closely, we see that each location in that block corresponds to a specific property of the pistons. Value number 2 in block 5 of a design file will always be the piston length. In this way we have achieved a simple means whereby programmes can communicate with one another, and information on a number of different designs. can be stored. It is only necessary for the programme writer to consult an index to discover the location of any property he wishes to reference.

(ii) Material properties

A similar philosophy was used for the material property files. In fact, two files were devised, one containing metal properties, and one containing fluid properties. The properties of a number of different metals are stored in the metal properties file in such a way that, by referring to an index, a programme writer can arrange for a programme to access any specific property. However, for reasons of security, the values in the material property files cannot be altered by the programme writer. (Further details of the material property selection method are given in section 7.3).

(iii) Other data files

As stated earlier, most of the remaining data files were peculiar to one programme, therefore it was only necessary to arrange for that programme to be compatible with the data file. Once again it was necessary to ensure that the data could not be altered by other programme writers.

This summarises the data structure used in the design system. The arrangement originally produced contained very little data, barely sufficient to allow thorough testing of the design system and data structure. However, having established these conventions, the structure could be developed and compounded as and when required.

7.3. Associated Programmes

7.3.1. File manipulation

The last section summarised the different file types constituting the data structure. Before this data structure could be considered part of the design system, two interfaces had to be created. Service software had to be written to allow programme writers to create and modify their own data files easily, and also subroutines were needed to link the design system programmes to the data structure.

The first of these interfaces was achieved simply, by writing three service programmes: one for creating data files, one for modifying them, and one for listing them. This then enabled programme writers to create structured data files to suit their own programmes.

The second interface involved the production of software to link the design programmes to both the pump design files and the material property files. The first subroutine produced enabled referencing and modification of any value in a pump design file. Thus, the programme writer had only to decide, at the programming stage, which parameters he was going to have read from the design file during the design run, and which of these he was going to allow the designer to alter.

Similar subroutines were produced for the material property files. However, here a strange situation came about whereby the programme writer, by using the appropriate subroutine, could decide which material property was to be used, but he was not allowed to influence the choice of material. This choice could only be made by the designer at the programme run time.

The operation of these subroutines is summarised in fig 7.3. These not only provided the interface required but also simplified the task of programming, and helped to standardise the form of interaction within the programmes produced by different programme writers.

7.3.2. Information retrieval system

The section above described how the programme writer could use service subroutines to manipulate parameters in the different design files and also how he could arrange to reference material properties in any of his programmes. A similar kind of flexibility was desirable for the designers and other design system users. That is, programmes were needed that allowed designers to reference material properties

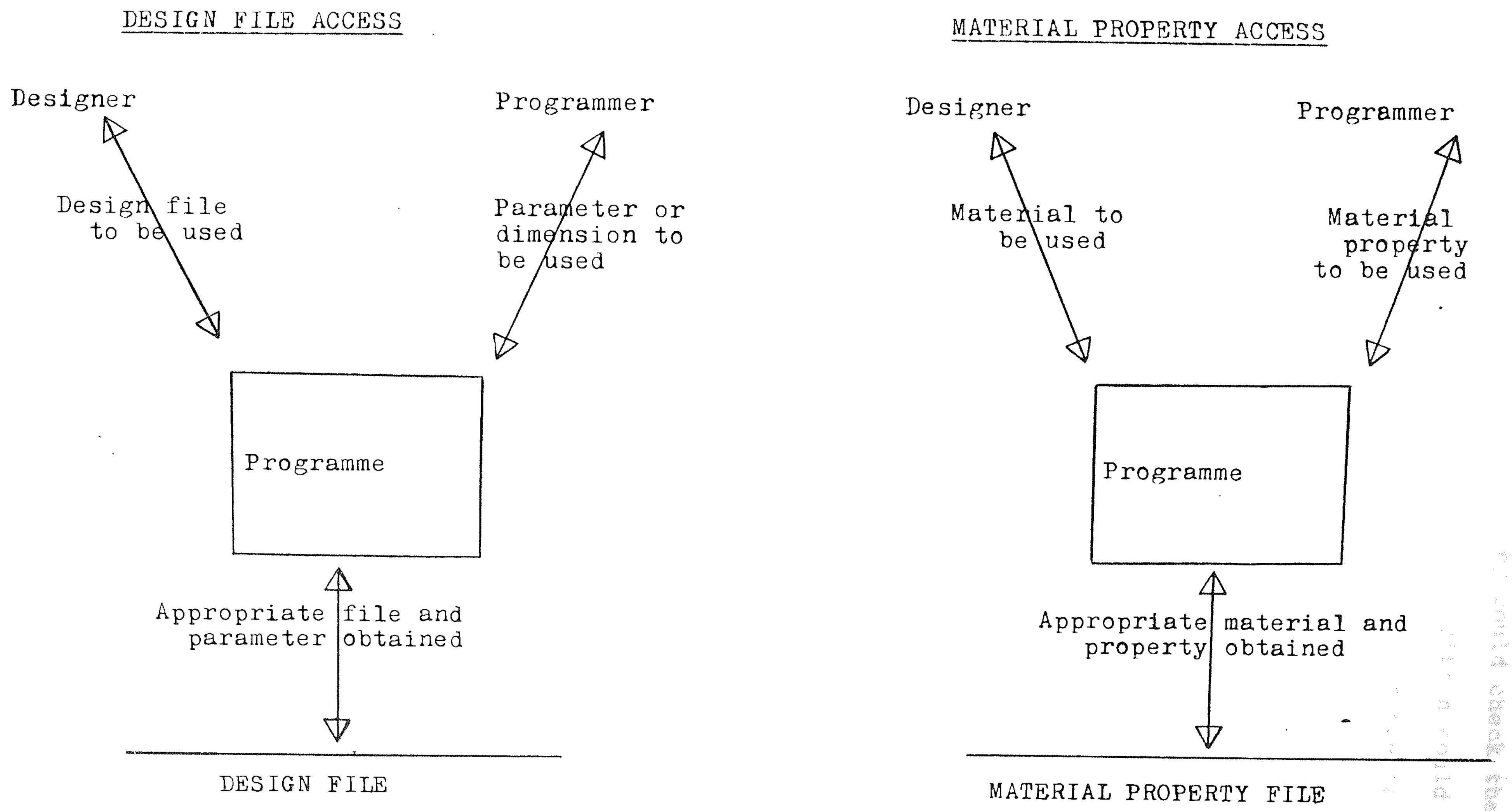


FIG. 7.3 Interfacing enabled by the file access subroutines

or list pump design files so that they could check their earlier decisions. Since any programme written could use the file access subroutines, it was trivial to arrange this kind of access for the designers. In fact, one such programme was written early in the development of the design system. This was the pump access programme PAP, which allowed the designer to examine the contents of a pump design file. By selecting the appropriate file name and the appropriate component from a list, the designer could arrange to have the properties of that component listed on the design terminal. This constituted the start of an information retrieval system, built on the data structure, which would later be developed together with the rest of the design system.

This completes a report of the work done on the project prior to installation of the minicomputer at the company, and therefore is the last chapter on this phase of the work. In the next part of the thesis the implementation of the design system into the company environment is described. Further changes to the design system are therefore treated as maintenance rather than development.

PART III

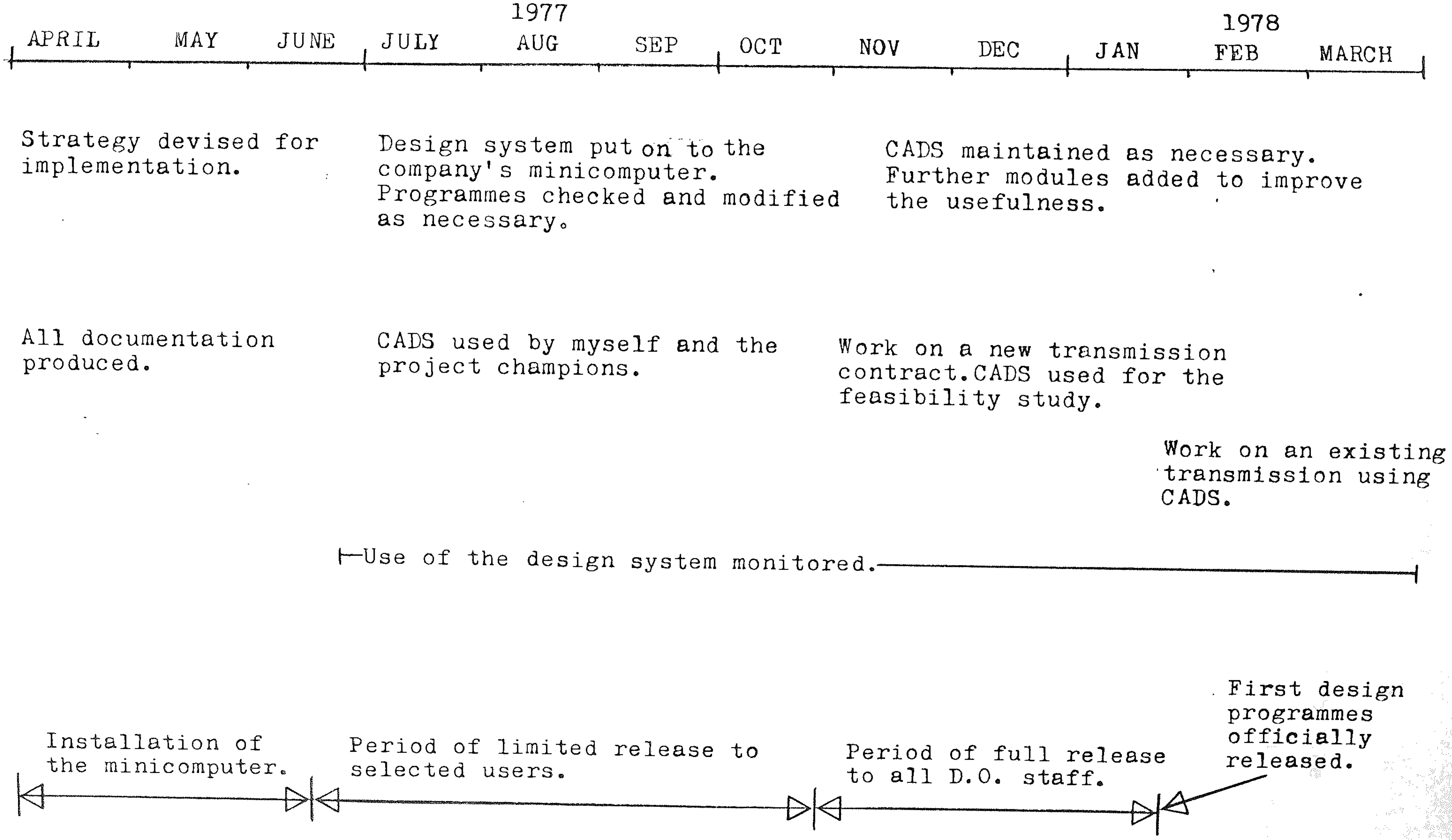
8.0. BACKGROUND TO THE IMPLEMENTATION OF THE DESIGN SYSTEM

In part II of this thesis, the structure devised for the computer aided design system (CADS) was described. The function and operation of the different programmes were explained and proposals were set out for a data structure to accommodate the design system. Most of these ideas were tried and developed using the mainframe computer of the University of Aston, but for the implementation a switch had to be made to the company's minicomputer.

Before implementation was begun, the design system was reviewed to determine what changes would be needed. Certainly much software would have to be altered, and the procedures for programme development would be different. Although the system had been planned for the design office environment, extra problems would certainly arise while developing the system within this environment. The fact that installation of the minicomputer, and implementation of the design system began simultaneously would also be a complication with confusions arising between the two.

This part of the thesis indicates the way in which the implementation was carried out. It describes the period from the installation of the minicomputer through to the maintenance and modification sessions necessary soon after the system had been fully released and used for design work. Figure 8.1 is a time chart of this period.

In this first chapter the scene is set in three stages: the installation of the minicomputer, familiarisation with the minicomputer system, and conversion of the design software. These stages are described in the next three sections.



Strategy devised for implementation.

Design system put on to the company's minicomputer. Programmes checked and modified as necessary.

CADS maintained as necessary. Further modules added to improve the usefulness.

All documentation produced.

CADS used by myself and the project champions.

Work on a new transmission contract. CADS used for the feasibility study.

Work on an existing transmission using CADS.

Use of the design system monitored.

Installation of the minicomputer.

Period of limited release to selected users.

Period of full release to all D.O. staff.

First design programmes officially released.

FIG. 8.1 Timetable of the implementation period

8.1. Installation of the minicomputer

8.1.1. Minicomputer purchased

The type of minicomputer system purchased by the company is a Digital Equipment Corporation PDP 11/34. This has 64K of memory and runs under RSX11D with DATS 11 software. Backing store is provided by two disc units. One of these is fixed, but the other can be removed from the system, enabling the loading of information appropriate to the work being done by the computer. The system is controlled using the master console, see figure 8.2.

Of the three user terminals, the graphics terminal is the one intended for design work as it allows not only text but also pictorial displays to be presented. This terminal is of the storage tube rather than the refresh display type (Davies [25] compares these types in detail); essentially this means that graphic presentations can be altered only by first clearing the screen and then plotting the modified display.

Finally, in order to obtain hard copies of the graphics, a plotter is provided which allows production of copies up to 2½ times as big as the graphics screen.

This was the arrangement on to which the design system had to be transferred. (Components of the computer system are shown in plates 8.1 to 8.4).

8.1.2. Intended functions of the computer

As already described, the main aim of the project was to provide an aid to pump design. This was to serve a number of staff with different specialisations, but was intended primarily to help designers, when trying to draught schemes to satisfy given performance specifications. The design system

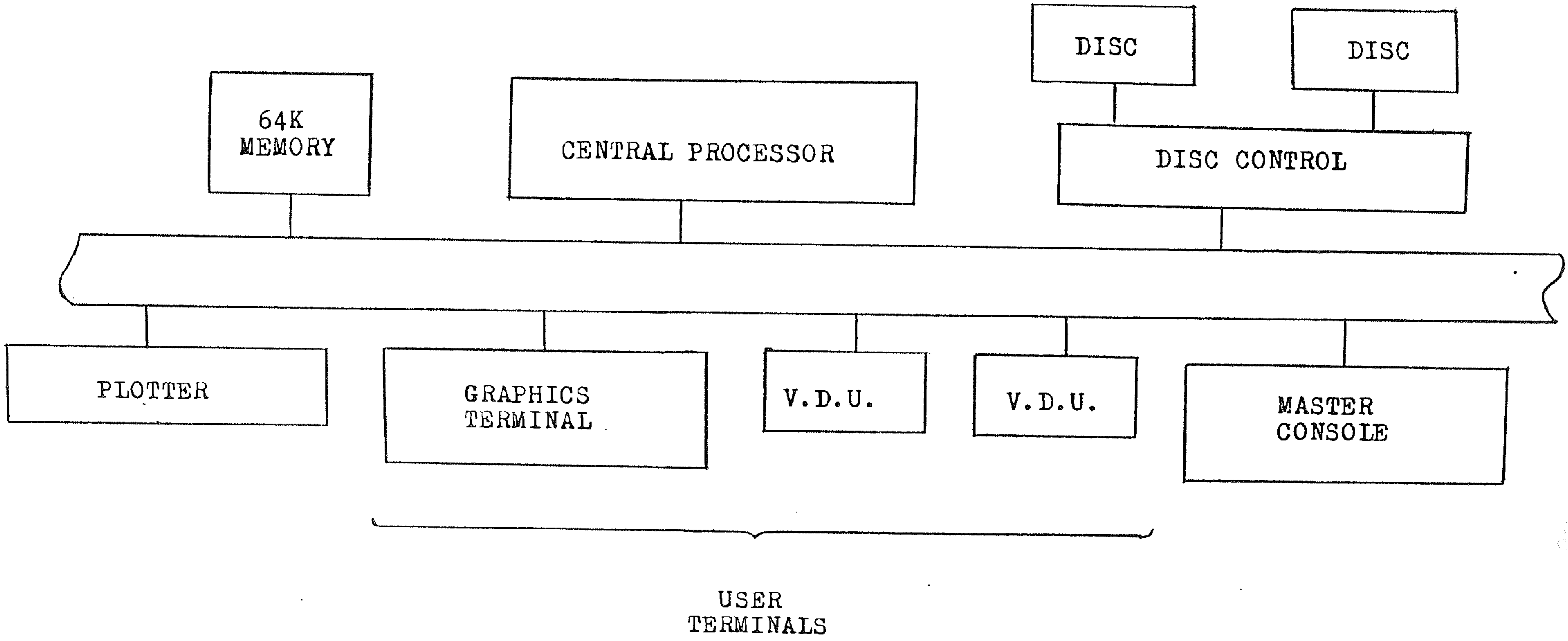


FIG. 8.2 Schematic of the minicomputer system

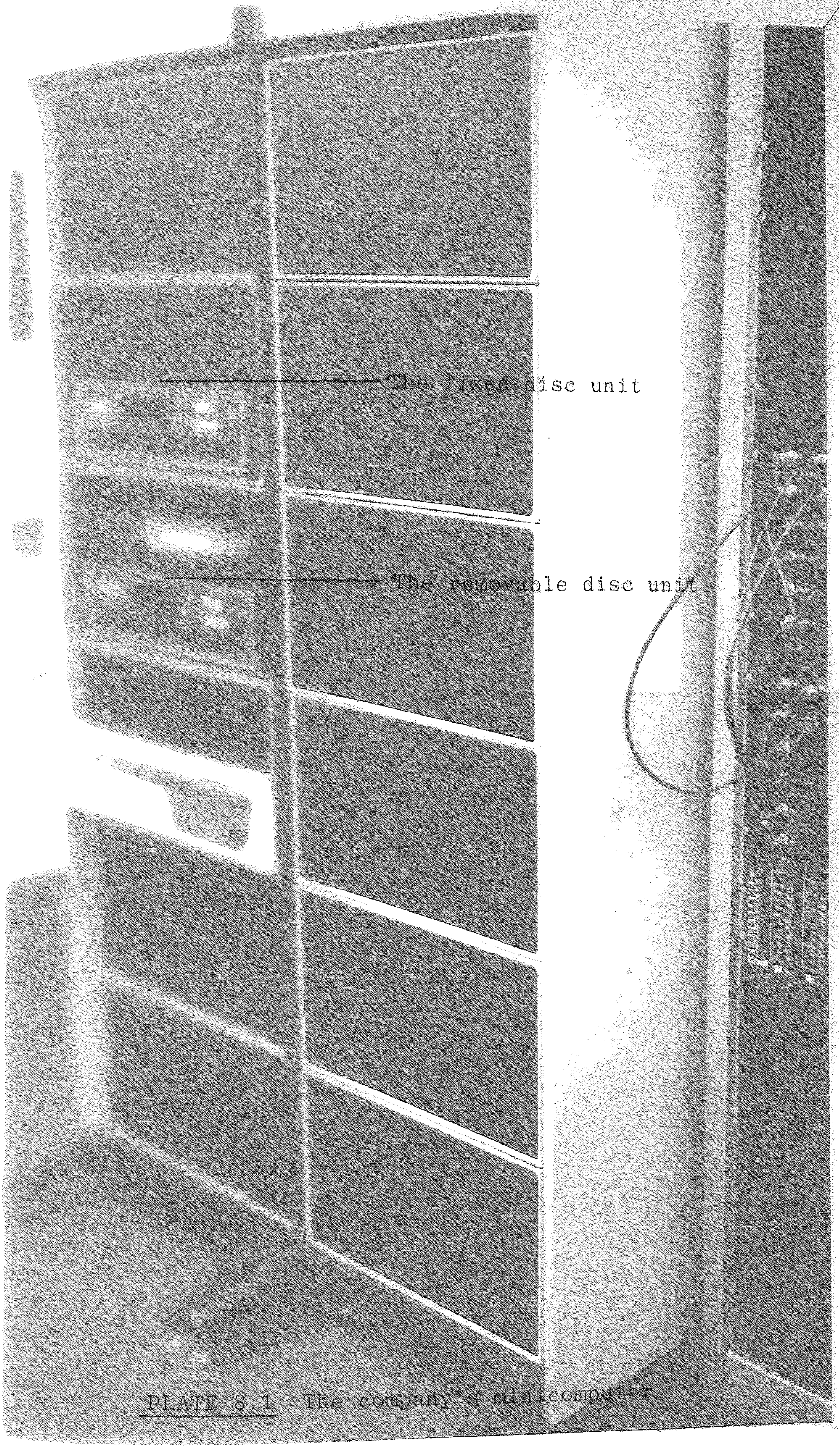
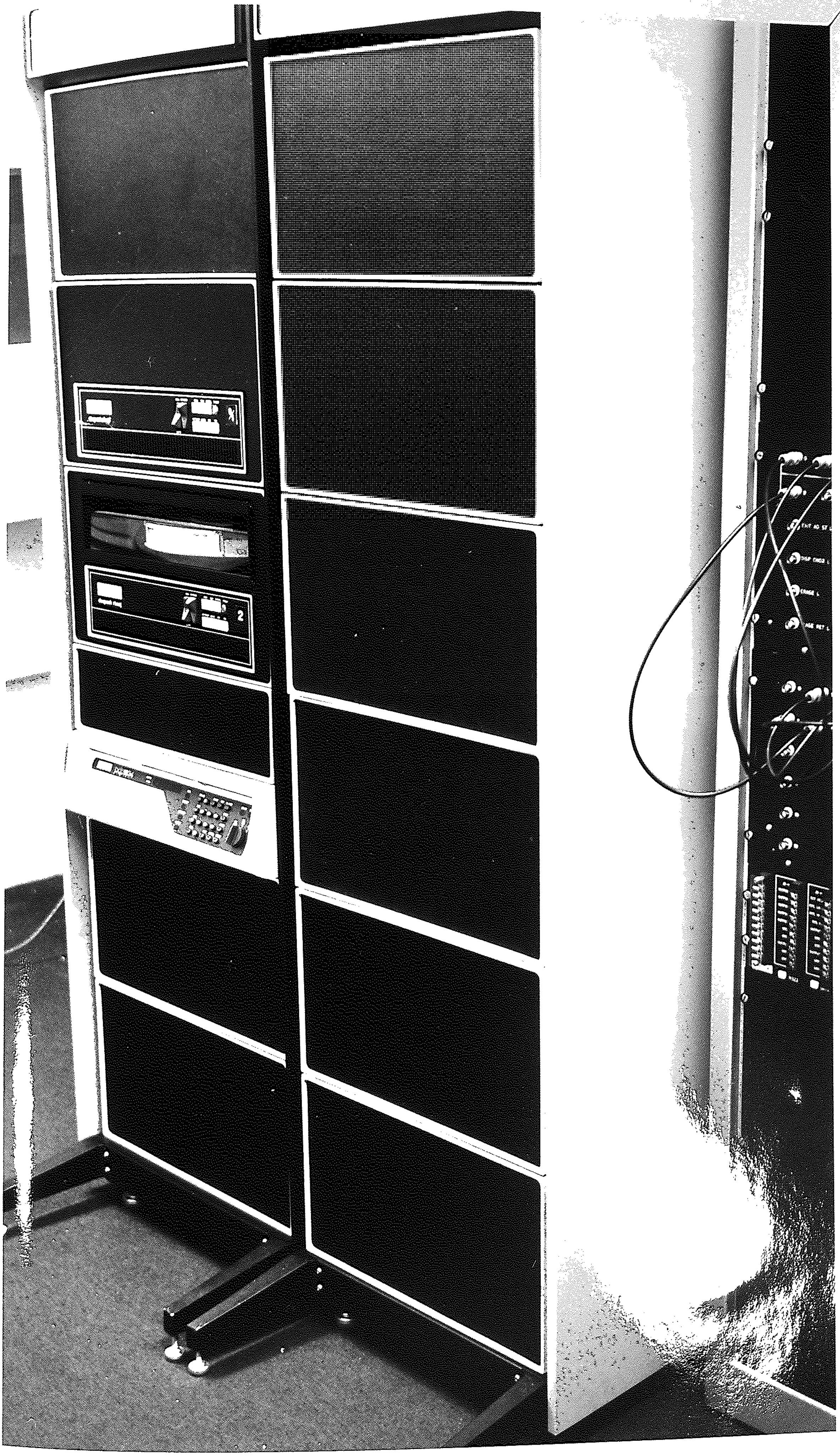


PLATE 8.1 The company's minicomputer



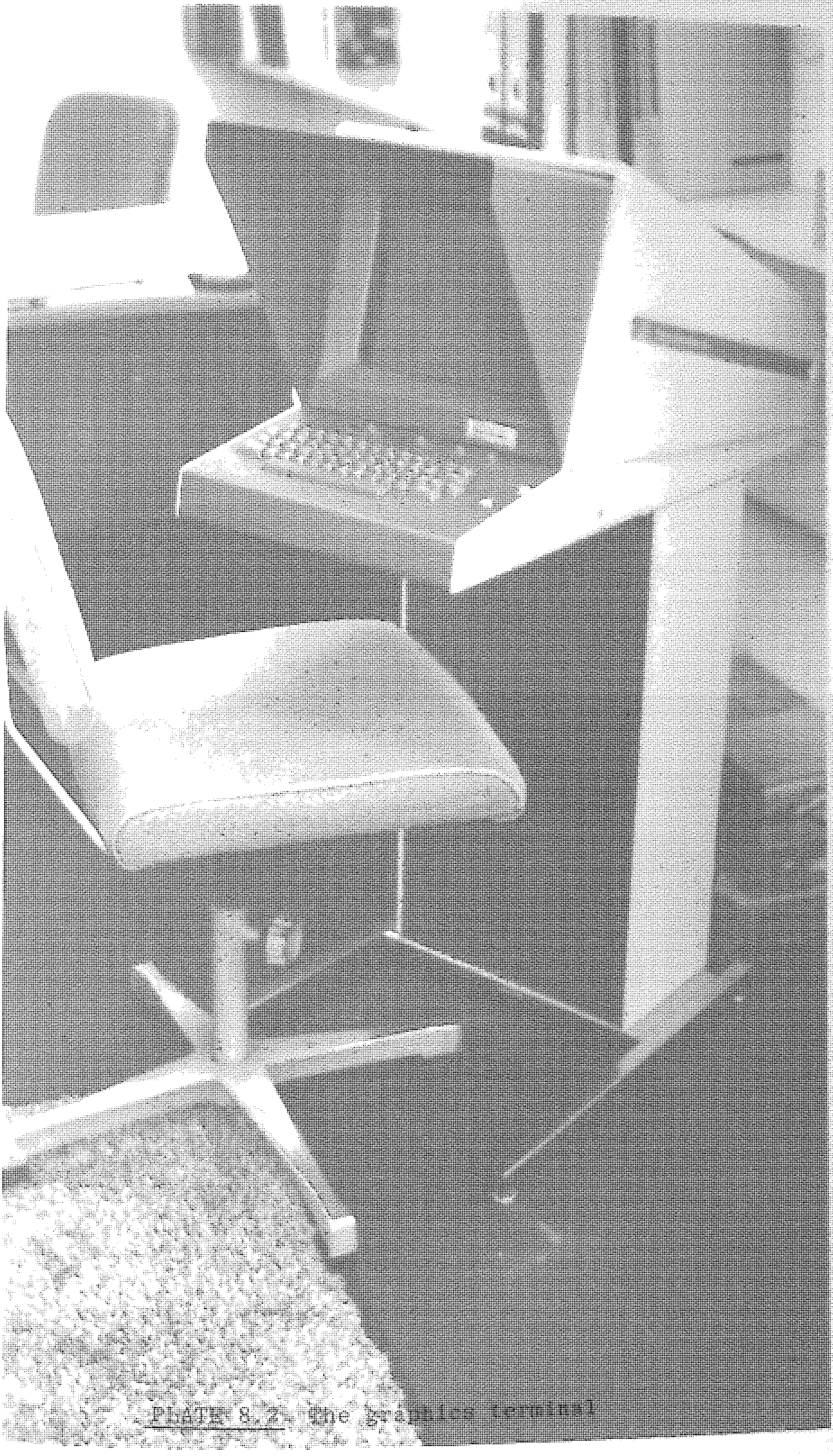
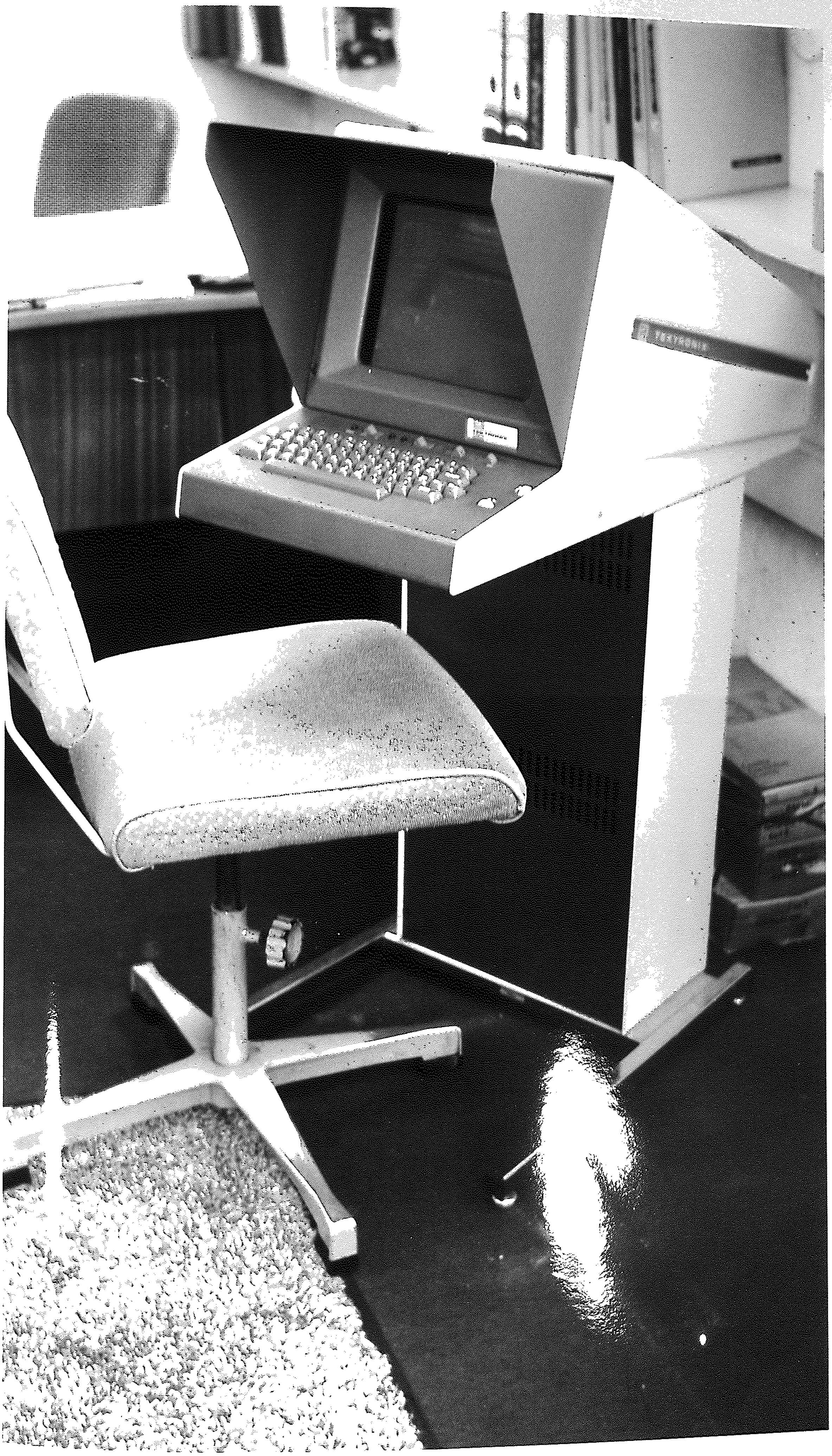


PLATE 8.2. The graphics terminal


TEKTRONIX

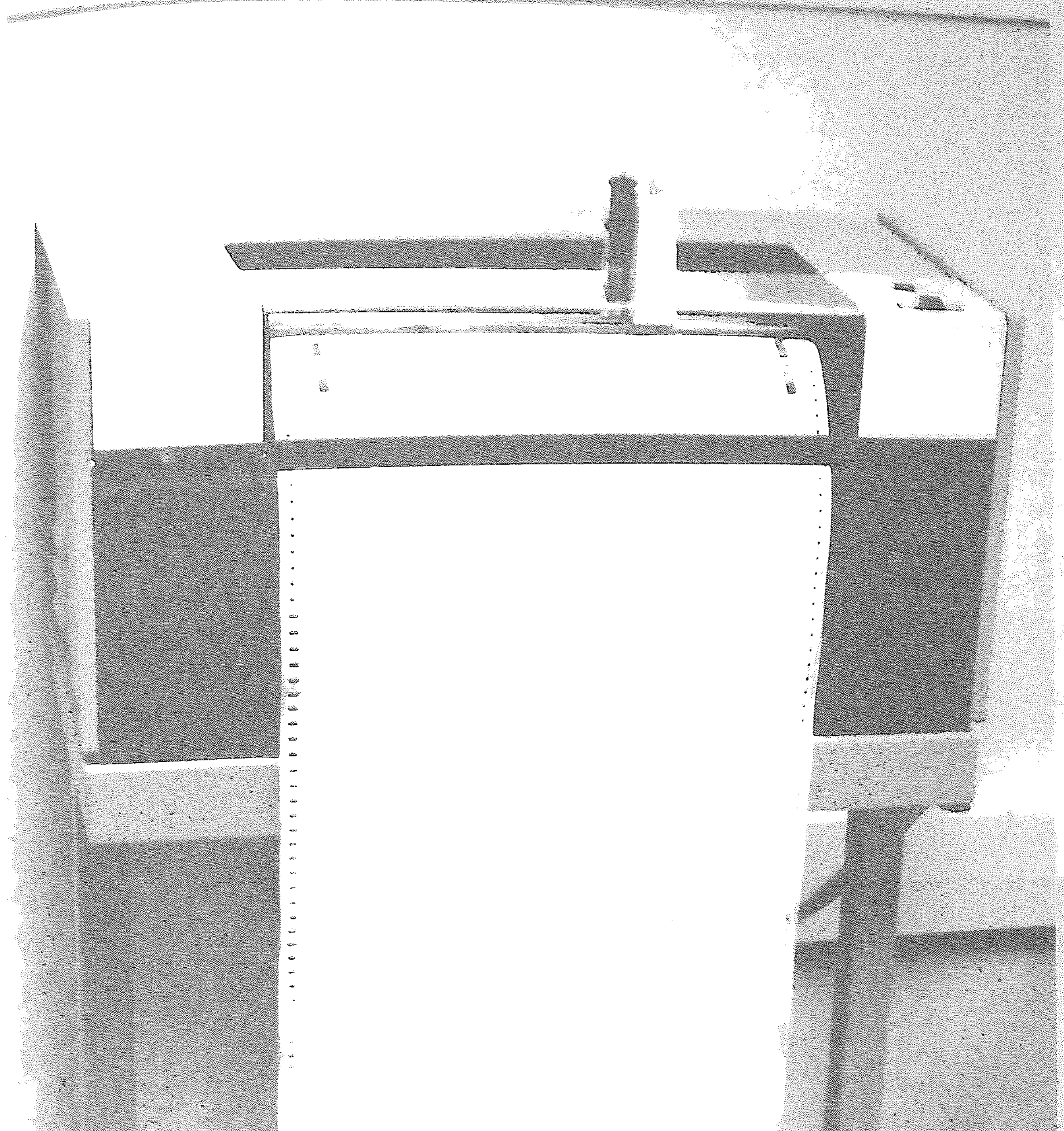
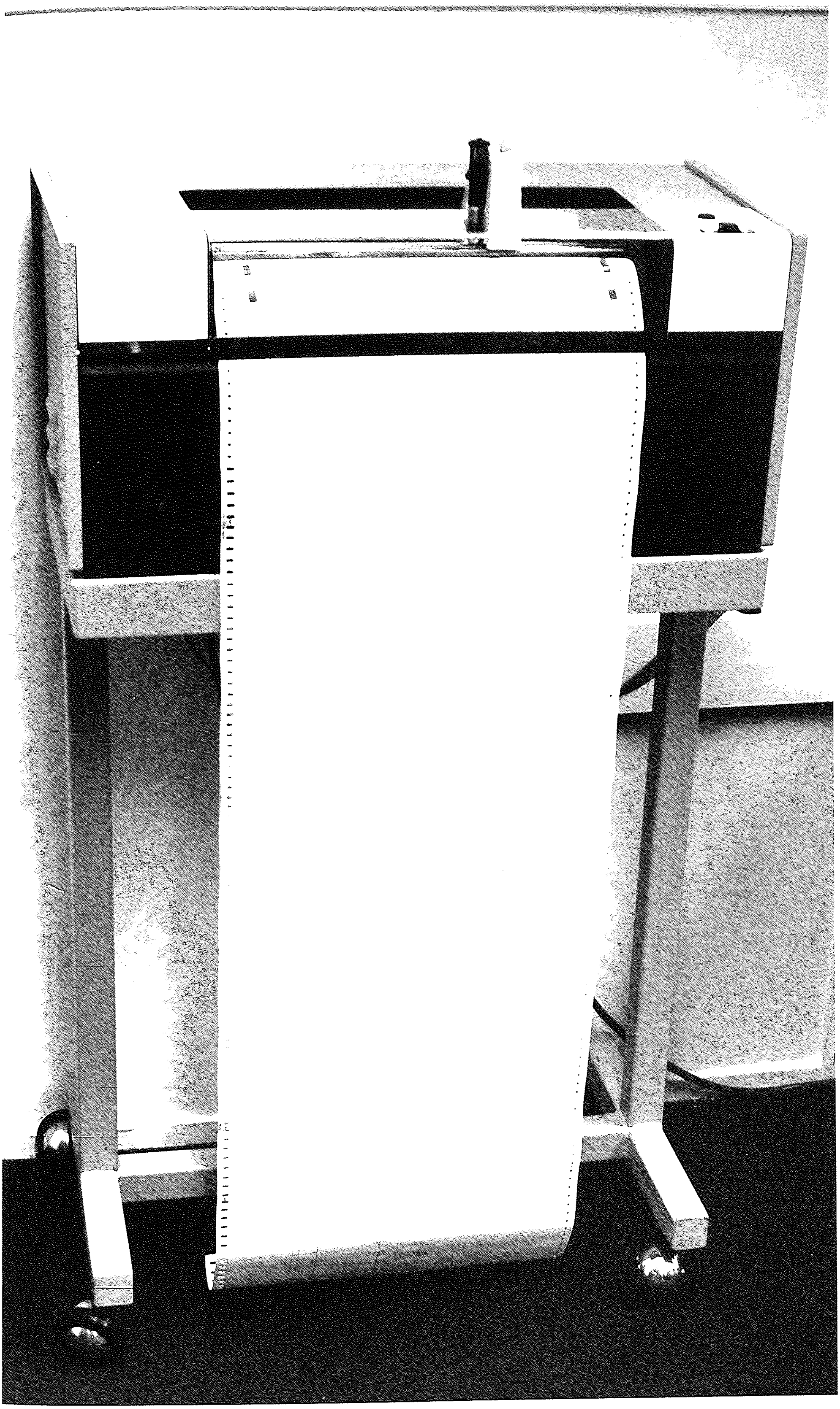


PLATE 8.3 The plotter



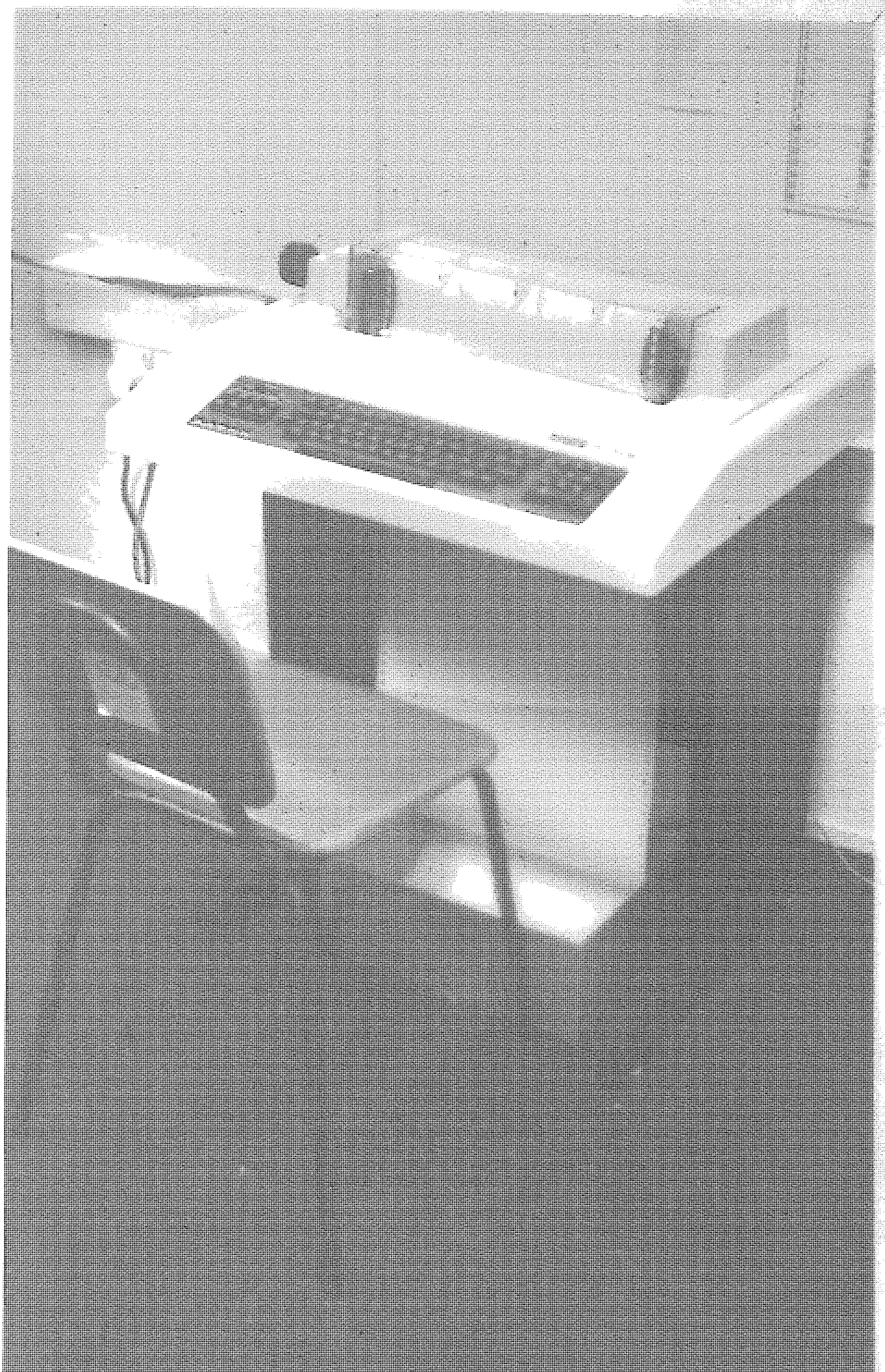


PLATE 8.4 The master console

had to be flexible enough to cater for these different users.

In addition to this there were two further functions of the computer.

Certain staff would want to use it for analysis work. They might want to analyse their own experimental data using the basic analysis software supplied with the machine, or indeed they might wish to write and use their own analysis programmes.

The computer was also intended to drive two experimental test rigs, that is, to control them, and log data from them at regular intervals. This task naturally had to take priority over the others and would make heavy demands on the minicomputer resources.

Time-sharing would enable all these tasks to be carried out simultaneously. In fact during the first few months after installation, neither rig programming nor analysis programming was being carried out, and hence during the implementation, the design work had a virtual monopoly on the computer.

8.1.3. Work-space arrangements

The minicomputer was a design office tool and was, therefore, housed in the design office. Despite a shortage of space, an attempt was made to locate it as sensibly as possible. Two separate questions were considered:

(i) Where should the computer be situated?

(ii) Where should the design terminal be situated?

The computer was housed in a purpose built room in one corner of the design office. This room provided the clean, temperature controlled environment necessary for the machine, and also attenuated the noise level. The design terminal (the graphics terminal) was situated just off the main gangway through the design office, (see fig 8.3). This location afforded the following advantages:

(i) The design terminal was readily available to all design office staff, and not absorbed into a particular group, e.g. development or research.

(ii) The terminal was conveniently near to the computer. This was useful, for instance, when hard copy graphics were being produced. It also meant that supervision or help was close at hand when the user needed it.

As shown in fig 8.3 a table was placed next to the terminal to enable the designer to conveniently reference drawings or make notes. Also the user guides and other reference information were placed on a shelf behind the terminal, within easy reach of the designer.

8.2. Familiarisation with the minicomputer system

The University of Aston computer system was arranged in such a manner that development and running of programmes was possible with only a little knowledge of the computer system itself. However, once the minicomputer was purchased, it was necessary to become familiar with many aspects of this new computer system in order to be able to use it effectively.

Different manufacturers develop their equipment in different ways. Thus, although decisions were made in part II of this thesis on the necessary structure for the design system, it was still necessary to see exactly how this

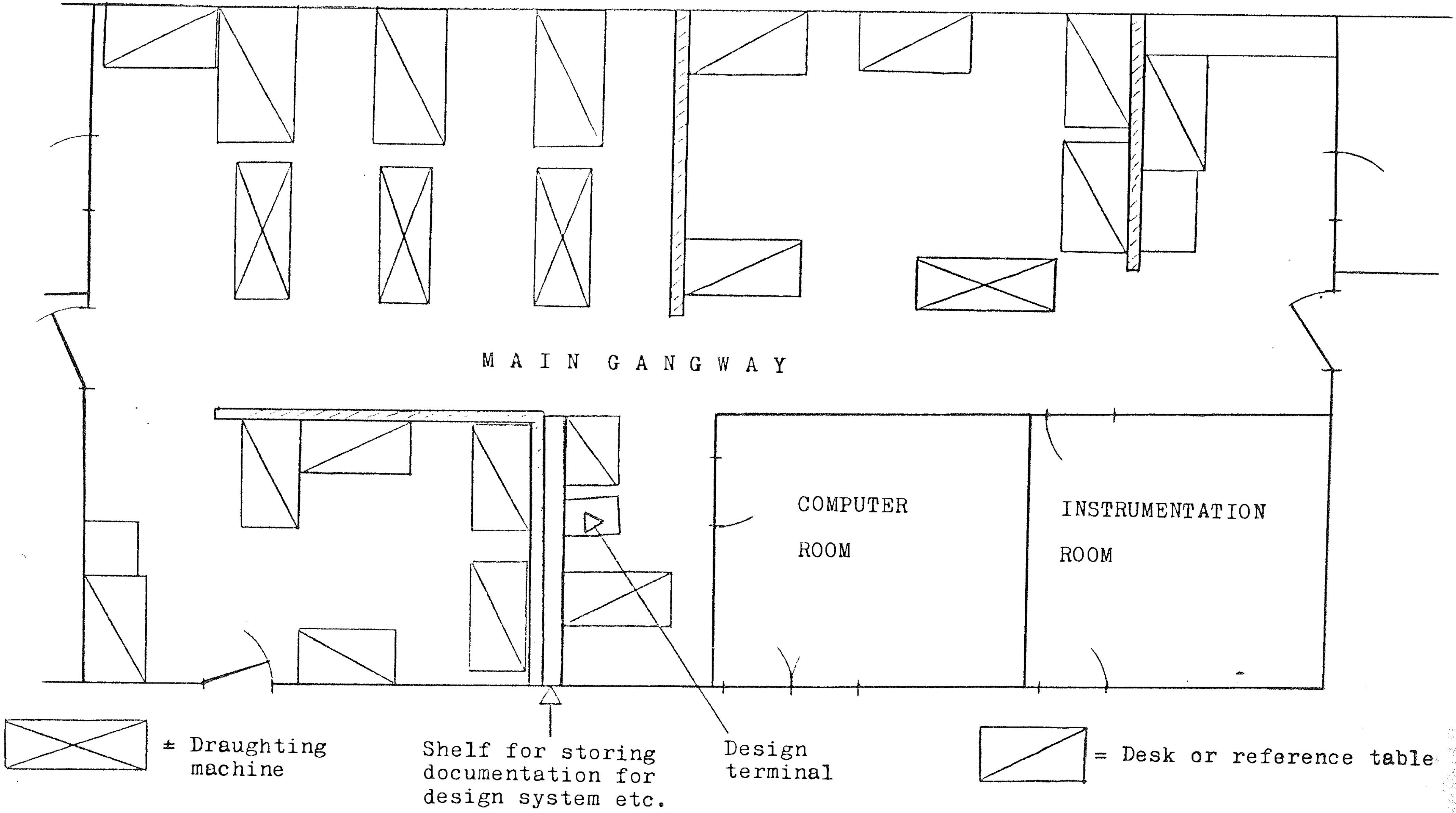


FIG. 8.3 Sketch of the design office layout showing the design terminal and the computer

structure could be accommodated by the minicomputer.

Fortunately an almost identical system to that purchased was in use at Southampton University prior to the installation of the company's system. Therefore, familiarisation was possible by observing this in operation. In this way some of the fundamental principles of this type of computer system were learnt e.g. file manipulation, programme development procedures. This then allowed a comparison between the Aston and minicomputer systems, and an assessment of the changes required to the design software.

After a short time it became apparent that differences between the Aston mainframe and the company minicomputer fell into two categories:

(i) Differences that were inherent because of the difference in size or type of the systems. Predominantly hardware differences).

(ii) Differences that resulted because of the different functions of the systems. (Predominantly software differences).

Once these differences had been clarified, it was possible to decide how the minicomputer system and C.A.D. software could best be matched. The salient differences are described in the next two sections.

8.2.1. Hardware

The main difference in this category was, that using the minicomputer it was possible to develop and run programmes interactively and hence very rapidly. (Essentially the university mainframe was intended to give a large number of users a basic computing service rather than to give a necessarily smaller number a rapid interactive service). Using the interactive graphics terminal of the minicomputer system, it was also possible to display graphic presentations immediately during the course of programme execution. These differences had already been anticipated in the production of the design software and consequently only minor adaptions were necessary.

The memory size of the minicomputer was a good deal smaller than that of the mainframe. In order to offset this disadvantage, on-line disc storage was available, but this had a random access time of milli-seconds rather than micro-seconds. Using the mainframe, it had been possible to have all of the programme and necessary library routines, along with any necessary data files, in memory at the same time, (although this was not the most economical way of using the computer). Using the minicomputer it was necessary to structure the programme and data files much more carefully in order to keep the memory size associated with a programme down to a minimum. Once again, much of this had been foreseen and the design system had been structured accordingly, as described in part II of the thesis.

8.2.2. Software

The software differences arose out of the different functions of the mainframe and minicomputer systems. The software provided with the company's computer system was biased towards the tasks of analysis and data reduction rather than design. This meant that graphical and textual presentations were orientated towards large quantities of numerical data. Alphanumeric information could not easily be handled. There was also no facility for manipulating graphical displays during programme execution. This facility is almost essential in design work where it is necessary to optimise and adjust before settling on a final design.

Once it was appreciated that these were only software differences, it was possible to set about writing the extra software necessary to cater for the design function. The extra software produced fell into three categories:

(i) Graphics subroutines

A suite of programme callable subroutines was written that allowed the programmers to display design charts of almost any description at any stage of the programme execution. By thoughtful programming using the new subroutines, a programme writer could allow the programme user to effectively manipulate the displays during execution.

(ii) Information retrieval

The file access software already discussed in chapter 7 was modified to bring it into line with the minicomputer file system.

(iii) Finally, other miscellaneous routines were written to improve terminal communication, and bring it to the standard suggested in chapter 6.

These subroutines which were written primarily for the design system, were of more general use to all programmers who might use the computer. Consequently, they were stored separately from the design system, as part of the computer system software.

8.3. Conversion of the design software

Before the conversion process was begun, a number of experimental tests were made using the minicomputer to assess how feasible different conversion proposals were, for instance, how much programme execution would be slowed down by disc accesses. When these tests were complete, the translation of programmes, from the Aston mainframe to the company minicomputer, began with the feasibility programme. The main aim was to translate most of the basic three stage system as rapidly as possible. Naturally, at the same time it was necessary to prepare the backup facilities: the data files, and library subroutines.

Once the basic design software had been translated and was operational, the data structure was expanded and the other programmes and options were added. The order in which the programmes were translated is set out in fig 8.4, however, more important than the order of translation is a record of the various steps involved in adapting each programme.

8.3.1. Programme adaptations

We have spoken of the programme conversion as though it were a single operation, however, there were really a number of steps which had to be taken successively. Thus, the overall conversion of each programme took one or two weeks.

During this conversion period there was a continual process of programme improvement and maintenance to overcome problems encountered. Excluding this complication for the moment, there were the following steps:

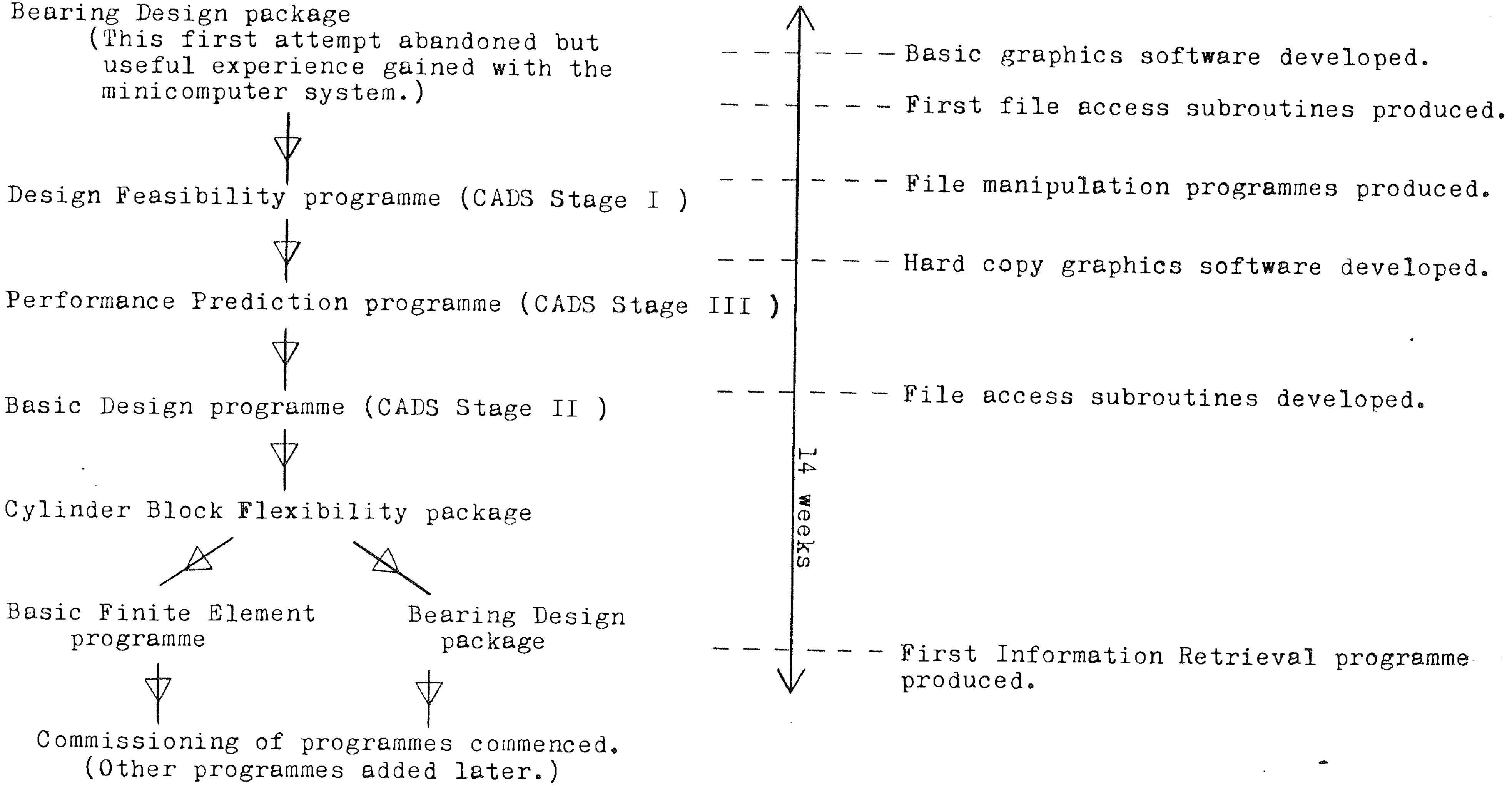


FIG. 8.4 Order in which the design programmes were translated

(i) Actual translation of the programme code
This was necessary because of the differences between the software of the mainframe and minicomputer systems. This category included changes in the input/output sections and file access. The changes were made, either because the original routines were unavailable, or because the change resulted in more efficient programme execution. Compiler differences necessitated further minor alterations to the programme code.

(ii) Preparation of backup data structure and subroutines for the design system.
There is by convention only one data structure and subroutine library for the system but, in the early stages of the conversion, the requirements of these backup resources were continually changing and it was therefore necessary to develop these as the conversion proceeded. Similarly, extra alterations to programmes were occasionally necessary to match them to the modified data structure and hence maintain the integrity of the system.

(iii) Overlaying
Once a programme had been substantially converted, then in order to reduce its memory requirement, it was overlaid according to the procedures of the minicomputer system.

(iv) Tidying the final programme

After the above alterations had been made, it was necessary to tidy up the programme both internally and externally so that it could be easily used, understood and updated.

These were the main stages in programme conversion. Along with this the documentation of the design system had to be produced and maintained, however, this will be discussed in later chapters.

8.3.2. Data structure construction

In the last section we mentioned the necessity for a single central data framework to accommodate the design system. The proposals for such a structure were made in part II of this thesis. It is worth noting now exactly how this was established in practice.

The first step was to develop the data manipulation routines necessary to the particular programme being converted. At the same time a "mock up" data structure was produced. This contained just sufficient data to prove the principle currently being explored. In this way it was possible to assess the adequacy of various ideas without having to create an entire file structure in each case.

Once suitable methods were found, the manipulation routines were developed fully, and more data was added to the data structure. This latter task was achieved using the separate file manipulation programmes described in chapter 7.

Finally, development of the information retrieval system described in part II was begun. All that then remained was was to document the work. Some of this documentation, for instance indexes of data files, was itself stored in the data structure. Further details of other documentation are given in the next chapter.

9.0. STRATEGY ADOPTED FOR THE IMPLEMENTATION

In the previous chapter the background was set for the task of implementing the computer aided design system. In this chapter various aspects of the strategy adopted for this task are described. These fall into the following categories:

(i) Computer system administration.
(ii) Limited release of the design system.
(iii) Training and documentation.
(iv) Monitoring methods.
(v) Security.

The original proposals for these categories are described in the next five sections.

9.1. Computer System Administration

A full description of the design system software was given in part II of the thesis. The modifications necessary to bring this into line with the minicomputer system were described in the last chapter. In the early stages of implementation, in addition to this programme development, development of the computer system was also necessary. In particular administration was necessary for allocation of user numbers, on-line disc space, and off-line disc storage. It was desirable to arrange this as early as possible to avoid the inconvenience and effort of later changes.

So far as disc allocation was concerned, it was clear how this had to be arranged for an efficient system. The fixed disc was allocated to the computer executive software, and the test rig programmes, as both of these had to be available for immediate use, at all times. The removable disc was thus available for all other tasks. One removable disc housed the basic design system software. This particular removable disc was left mounted on the computer most of the time, so that the design system was also usually immediately available. However, when it was desirable to use a programme which was stored on a separate disc (e.g. the finite element programme) then the design system disc was temporarily removed from the computer system.

Each computer user was allocated a unique user number. (The design system was also allocated a separate user number for the use of those concerned with design system development). The responsibility for the tidiness of a user's own file store of programmes and data was left with that user, but a limit was set on the amount of disc space available to him.

General purpose software was also stored under a separate user number, but made available for use (but not alteration) by all users. Hence each user had both the use of the design and general purpose software, and the facility for keeping his own personal data, results and programmes.

9.2. Limited Release and Project Champions

Soon after installation of the minicomputer, a strategy was devised for introduction of the design system. The argument for this strategy was as follows.

In the early stages after implementation of the design software, while rapid development was continuing, the design system would be in no state for general release. It would have to be tried and tested over a period, and modified as a result of problems of use. Nonetheless, during this period, an increasing amount of useful design software would become available.

To enable this software to be used, the concept of project champions was adopted. (The usefulness of project champions in launching new ventures is described by Langrish [26]). These people were links between the new design system and the remainder of the design office. They had a knowledge of both engineering and computing, and their function was two-fold:

(i) They were to run the design programmes in order to discover any shortcomings in their operation. Suitable improvements could then be made.

(ii) They were to make live runs to produce information of use to the design office.

To enlarge on the first of these points, it was essential that the design software was as correct and acceptable as possible before it was generally released for design office use, otherwise much criticism and disillusionment would ensue. The project champions would be able to assess the adequacy of the design system, and their knowledge of computing would ensure that their suggestions were realistic.

The second point above concerned the provision of a useful design aid for the design office while the software was being developed. The project champions would be allowed to use the design programmes for themselves and for others during the limited release period, and would thus provide the other designers with useful results before general release. This would both benefit the designers, and provide further feedback information as to the adequacy of the system.

The plan was, that the period of limited release would extend over the software installation and commissioning phases, an estimated duration of three to six months. At the end of this period full release would begin.

9.3. Training and Documentation

The training of design system users was split into two parts:

(i) Training to become conversant with the design terminal, and to a lesser extent the computer system.

(ii) Training to use individual design programmes effectively.

The basis for this training was comprehensive but succinct documentation, along with personal supervision during design runs. The design system was documented at two different levels corresponding to the two parts of the training listed above. (The separate programme descriptions intended for programme writers are not considered here).

The user documentation consists of the CADS (computer aided design system) series of reports listed below. All of these reports were written in the second person in order to make them clearer and less formal.

CADS - Designer's reference guide

CADS - Description of design feasibility programme

CADS - Description of design programme

CADS - Description of pump performance programme

CADS - Description of information retrieval system.

The first of these reports (see appendix D) describes the overall structure of the design system and also explains how the user should communicate with the design terminal. After reading this report, the user should feel confident to sit at the terminal and experiment with the design system. Supervision at this stage should be minimal, the mere presence of somebody that can help should give the user sufficient confidence to master this part of the training alone.

Having familiarised himself with the overall design system structure, the user will want to become conversant with a particular design programme. This second part of the training is covered by the second and subsequent CADS reports.

The structures of all of these CADS programme descriptions are identical. There are two main sections, one describing how and for what purpose the programme should be used, the other describing how the programme does this: essentially the theory of each part of the programme. These usage and theory sections are cross referenced, so that at any time the user may turn from the usage section to the theory in order to ascertain what the computer is doing for him.

The second part of the training might require slightly more supervision than the first for two reasons.

(i) The CADS programme descriptions will naturally contain omissions or ambiguities - certainly the first editions will.

(ii) The user will have gained confidence with the system and will be less likely to thoroughly read the documentation.

In general, the supervision should consist of clarifying points made in the programme descriptions, and referring the user to salient parts of the usage or theory sections. It might also be necessary to demonstrate how each programme should normally be used in order to teach the user some of the techniques of running the programmes. To begin with the user will probably work on existing established designs, so as to become fully familiar and confident with the programmes. Later he will want to try out some of his own ideas with new or modified designs.

The intention was that user training would begin towards the end of the limited release period, when it was felt that the design software was ready for general release.

9.4. Monitoring methods

In chapter 3, it was explained that it would be necessary to carefully monitor the use of any new design system, for two reasons: first this information would be necessary for the maintenance and improvement tasks, and secondly, it would constitute an important part of the data for evaluation of the project.

Three methods of monitoring were planned. The first was to keep a daily record of, the work being done on the system, the problems encountered by users, and the responses of other design office staff.

The problems encountered and the criticisms would be logged separately to expedite maintenance sessions. During these maintenance sessions the aim would be to disturb the outward appearance of the system as little as possible, so that the user's operating instructions were not altered. Initially a programme would be monitored for a week or two before any modifications were made. This would avoid repeated alteration of programmes.

The second method of monitoring entailed the use of verbal protocol. This consists in the user being asked to speak his thoughts aloud as he uses the system. This would provide information on two aspects of the design system.

(i) The efficiency of communication between the user and the computer.

(ii) The usefulness and flexibility of a particular design programme.

This method would be used with both project champions and other users.

The final method of monitoring was to interview the users, both before and after release of the system. In this way, the change in attitude of the users might be determined and this would give an indication of the acceptability of the system.

These were the three monitoring methods adopted. They will be expanded, and the results obtained will be given in later chapters of the thesis.

9.5. System Security

The last aspect of the implementation to be planned was that of security. This covers a wide range of problems, some of which can be dealt with very quickly. The fundamental security requirement was that the design system software, and each user's personal file store, was safe from accidental loss or tampering.

Security against a computer fault or disc breakage was accomplished simply, by copying the working discs on to backing discs regularly (say once a week). Thus, the most that could be lost was one week's work.

The privacy of a user's own files was facilitated by allocating him his own user number. This was described in section 9.1.

The other aspects of security were concerned with protecting the design system from the users. To achieve this it was necessary to distinguish four levels of authority for making design decisions. These were:

(i) To make non-trivial design decisions during the course of a design session.

(ii) To alter temporarily, those standard design parameters and constraints usually regarded as fixed.

(iii) To alter permanently the parameters and dimensions in a pump design file.

(iv) To alter permanently the standard design parameters mentioned in (ii) above.

Corresponding to these, several levels of authority of use were distinguished. These levels were realised by allocation of user numbers. The first level of authority was granted to all designers that wished to use the design system, but all other levels of authority were reserved for more senior engineering staff by means of privileged user number allocation. In this way, fundamental changes to the design system could only be made with the consent of a senior engineer. This considerably reduced the possibility of the design system becoming corrupted during normal use.

This then summarises the strategy that was adopted for the implementation. The two chapters that follow describe how this phase proceeded in practice, and the problems that arose.

10.0. PERIOD OF LIMITED RELEASE

Once the minicomputer had been installed at the company and all of the software had been converted, it was then necessary to re-commission the design system prior to releasing it. As suggested in the last chapter, this was done during the period of limited release.

Numerous design runs were made with the programmes in order to assess their adequacy and, towards the end of the period, a full CADS design run was carried out for one particular pump model.

The four sections of this chapter describe most of the work done by myself and the other project champions, using CADS during the period of limited release.

10.1. Commissioning the CADS programmes

This section explains how the operation of the CADS programmes was checked after conversion of the software. This was necessary to ensure that they had not been contaminated during the switch to the minicomputer. It was also the last full check of the system before limited release to the project champions. The design system components to be checked were: the feasibility programme, the design programme, the performance programme and the stand alone packages such as the bearing design package. It was also necessary to check the finite element programme allied to the design system.

Some of the early problems encountered during the commissioning were due to trivial programming errors. These were manifested by execution errors or the occurrence of impossible results (e.g. negative dimensions) when the programme was run, however, most of these were taken account of during the normal programme development and are not discussed here.

10.1.1. The feasibility programme

The method used to check the feasibility programme was to run it for the company's existing established designs, to ensure that their adequacy was correctly predicted. To do this it was necessary to make decisions, in reply to programme prompts, consistent with the geometry of the existing design being used. Therefore, this constituted an unorthodox use of the design system, but was satisfactory for checking the validity of the programme. At the same time it was possible to assess how readily the original designs could be uprated and these results were compared with the actual uprated designs. An example is given in fig 10.1; this clearly shows the inadequacy of the original design for the uprated specification. Three factors combined to give the feasible design chart shown in fig 10.1 c:

(i) Modifications were made to the geometry of salient components of the design.

(ii) Different materials or material treatments were used for critical components.

(iii) One of the design constraints (the head loss constraint) was relaxed as a result of experience gained with previous models.

By these means, the allowed area on the feasible design chart was restored.

Once confidence in the programme had been gained, it was then possible to use it in order to discover whether

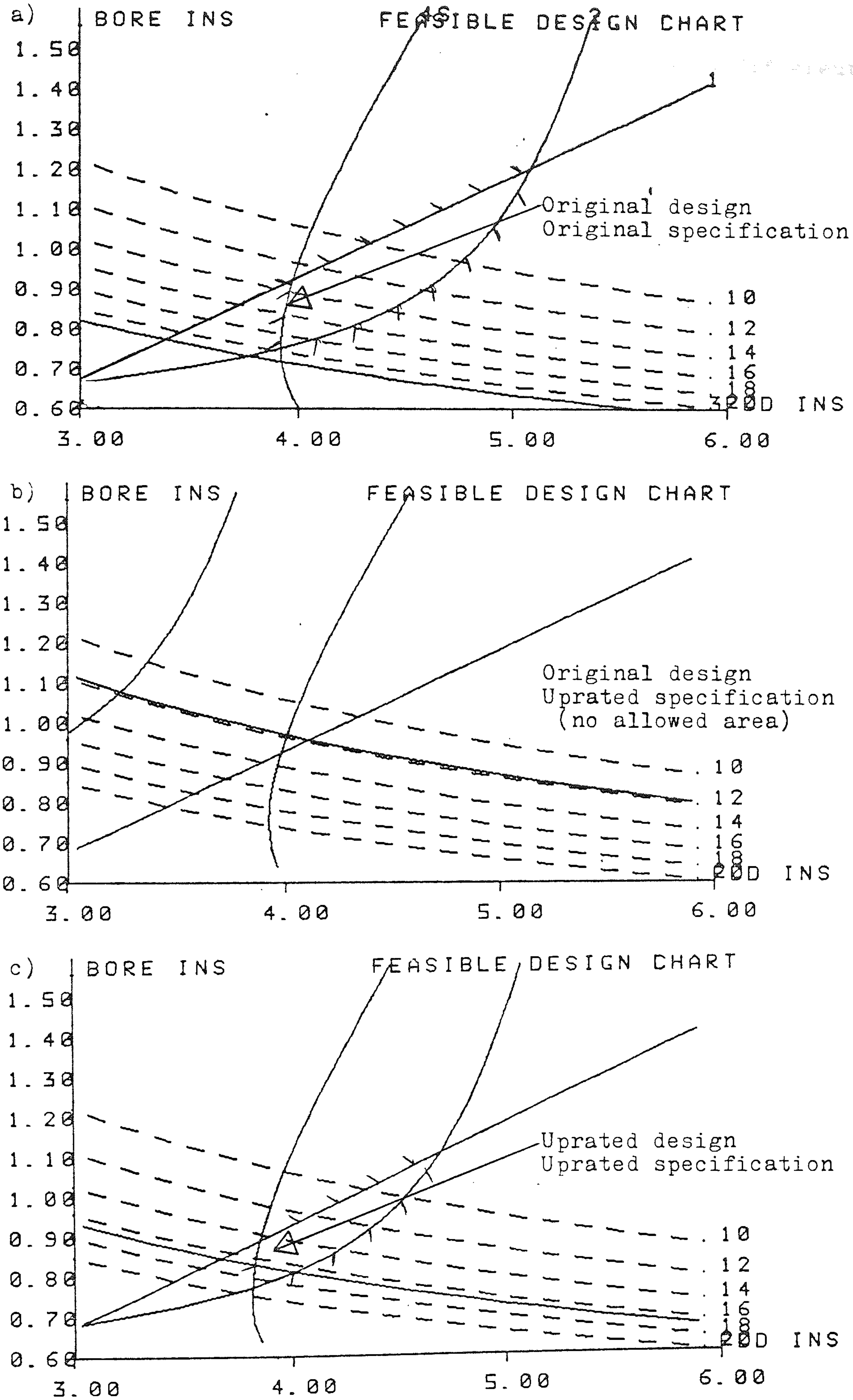


FIG. 10.1 Uprating of an existing design

designs could be uprated still further, or whether a different choice of basic geometry might have resulted in a model more amenable to uprating. Three alternative designs, produced using the feasibility programme in this way, are shown in fig 10.2. Although some of these alternatives appeared quite feasible, additional criteria (such as size, volume, and the extent to which standard parts could be used) made them less attractive than the adopted design, (fig 10.1 c).

10.1.2. The Design suite

As described in part II of the thesis, the main purpose of the design suite was to allow development of the design chosen at the feasibility stage, until a sketch of the running gear of the pump could be produced. The design programme could thus be partially checked by developing a design, which had been produced using the feasibility programme, in order to ensure that the geometric predictions of the two programmes agreed. Further checks were made by separately evaluating design equations used in the programmes and comparing these with the computed results.

In addition to assuring the validity of these geometric design sections, it was necessary to check the accuracy of the two analysis sections. These were the flexibility analysis and bearing design packages. It was desirable to compare the predictions of these with the results obtained by some independent means.

In the case of the flexibility package, the method used was to assess the flexibility of various cylinder block geometries, first using the flexibility package and then using a finite element package. As shown in fig 10.3 the

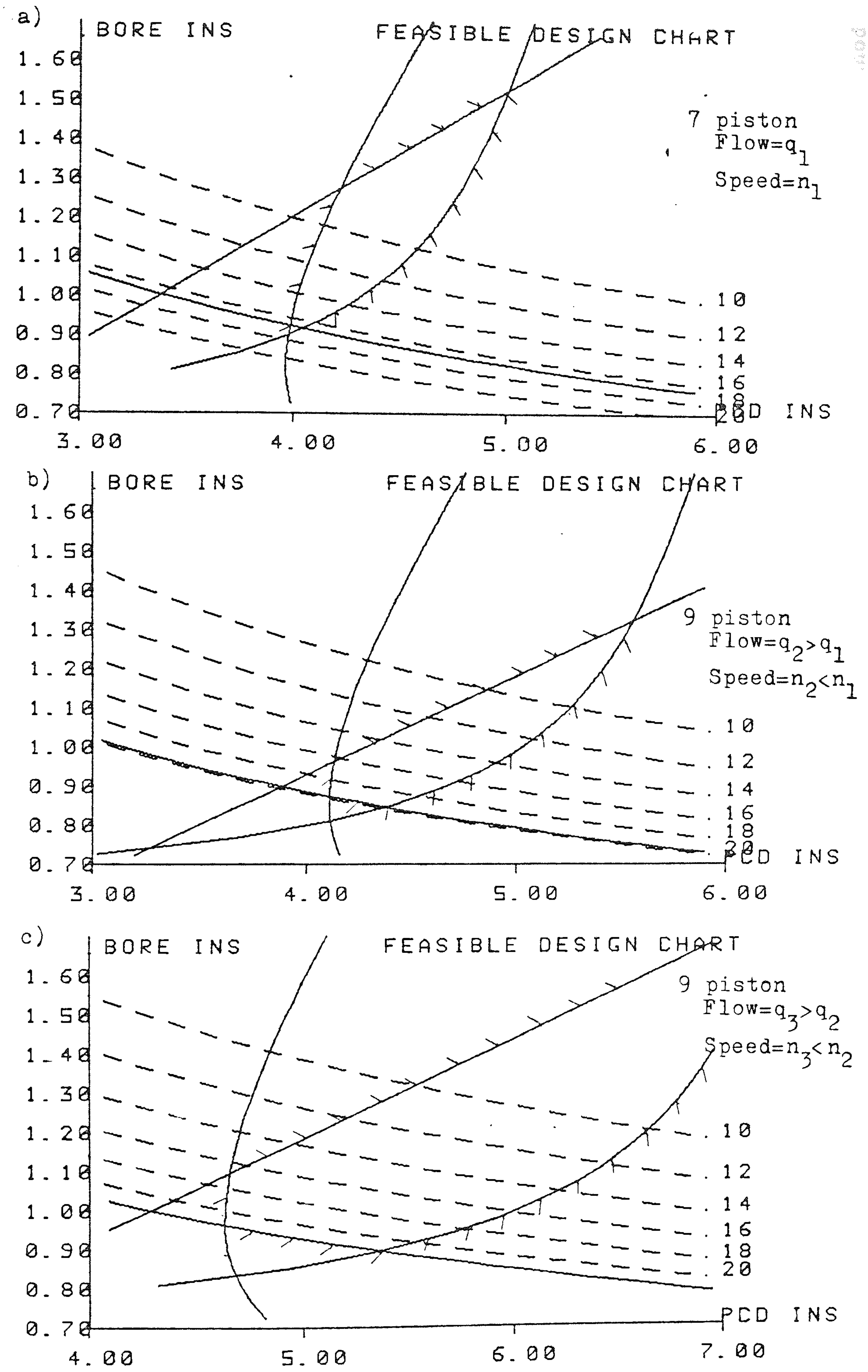


FIG. 10.2 Three alternatives for the same specification

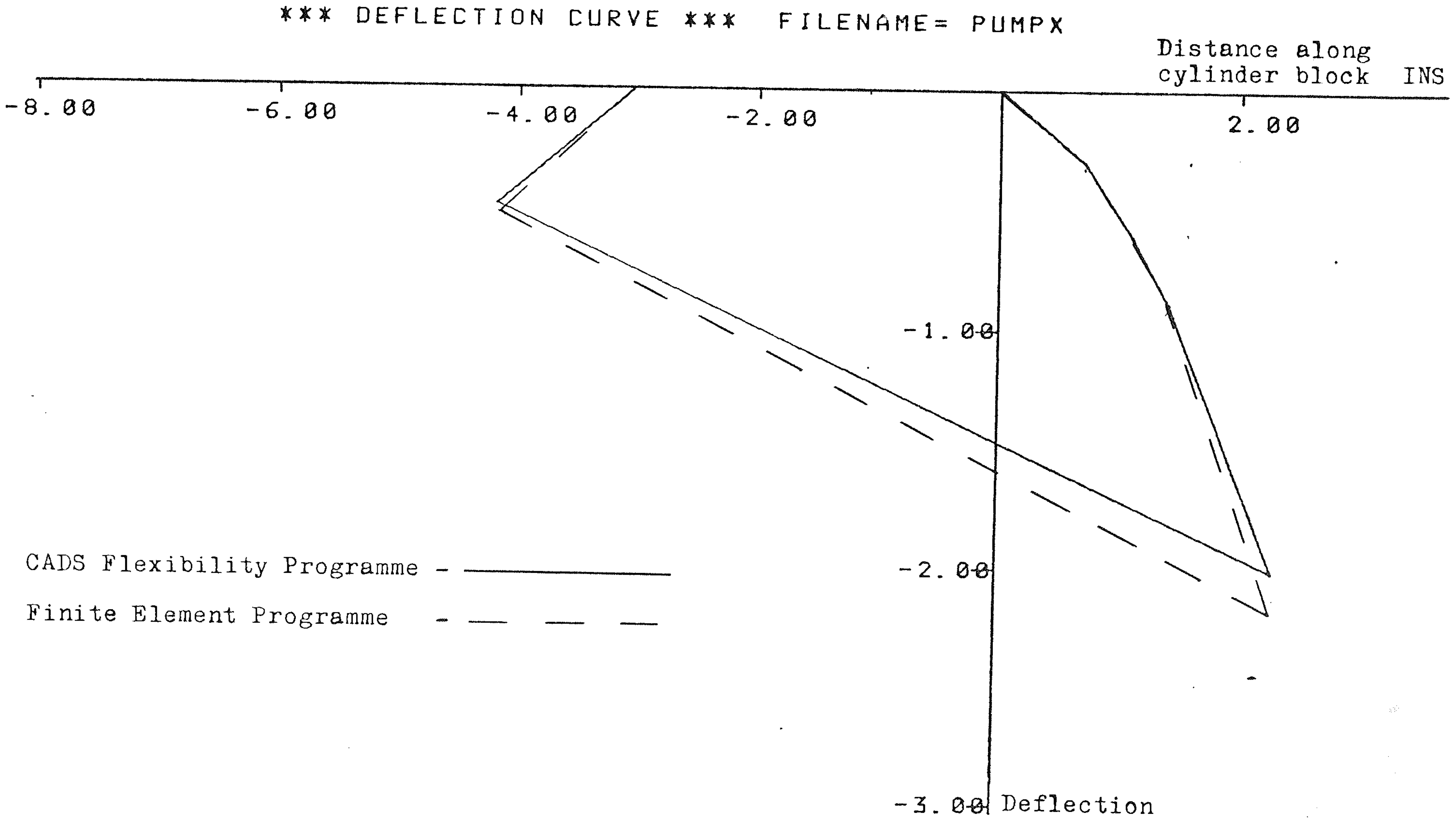


FIG. 10.3 Comparison of cylinder block deflection predictions: CADS v Finite Element method

results agreed to within 10%. This correlation was quite adequate for the purpose of comparing alternative designs.

In the case of the bearing package it was more difficult to find alternative methods of analysis for comparison. The method eventually chosen was to compare the results from the design package, with those obtained by the Glacier Metal Co. Ltd. using their own bearing analysis programmes. A comparison of the results obtained for an existing pump run under heavy loads and at high temperatures is shown below.

	Eccentricity		Average Temperature Rise C	
	CADS	Glacier	CADS	Glacier
Case 1	.87	.87	20	15
Case 2	.95	.94	15	10
Case 3	.95	.95	30	21
Case 4	.98	.96	25	15

TABLE 10.1 Correlation of the bearing performance results

There were discrepancies between the temperature predictions of the two methods, but in view of the extreme conditions for which the results were obtained, the correlation was reasonable. The package was, therefore, considered suitable for determining the adequacy of different bearing configurations.

10.1.3. The performance programme

As described in part II of the thesis, the performance programme was intended for the evaluation of different design proposals produced with the design suite. Correlation between the theory of this programme and experimental results had been undertaken by Madera[22] when he first developed the programme. To commission this programme, it was thus only necessary to ensure that the CADS results agreed with those originally obtained by Madera. Having established this, the programme was then used in earnest in the design system.

Commissioning of the separate finite element programme was equally straightforward. This programme had been adopted from a version which existed on a mainframe computer, the programme size having been reduced to suit the smaller computer. The programme was checked by analysing elasticity problems not concerned with pump design, but for which exact solutions were available. Since the basic operation of a finite element programme is independent of the shape and size of the subject of analysis, this was sufficient to justify its subsequent use for analysing elasticity problems in pumps.

10.2. "3.2" Model Design Study

The "3.2" model pump was the subject of a full CADS design analysis. This was the same model as had been used in the "user trip" described in chapter 3. In fact the final design of the unit had eventually been completed at a United States division. The design study now described provided an opportunity to compare the design obtained from the new design system with:

(i) Those designs produced by myself and others during the original design study.

(ii) The final design drawn up in the United States.

10.2.1. The original design study

Early in the project I undertook the design of the "3.2" model at the company. The time taken to produce a provisional scheme layout was four weeks. The design method used was described in chapter 3 and summarised in fig 3.2. This figure shows how the various design criteria defined the order in which the pump components had to be designed. The complexity of the task inevitably meant that trial and error had to be used to satisfy some of the criteria. In fact my first design attempt was unsuccessful. A geometric inconsistency was encountered, as shown in the figure, which could not be resolved without complete re-design. The second attempt, however, was successful; the resulting scheme layout is shown in fig 10.4.

After this user trip, I examined some of the alternative schemes that had been produced by other junior designers who had attempted the design previously. (To have examined these earlier would have influenced my own design attempt). The total number of schemes produced by these designers was six, although four of these subsequently proved geometrically inadequate. These schemes provided a wide range of alternatives, however, none of them were developed or evaluated. Probably the main reason for this was that there was no accepted method of comparing alternatives, that is, no way of quickly developing each scheme to the stage where its performance could be directly compared with the other alternatives.

10.2.2. Design of the "3.2" using CADS

During the period of limited release, CADS was used to

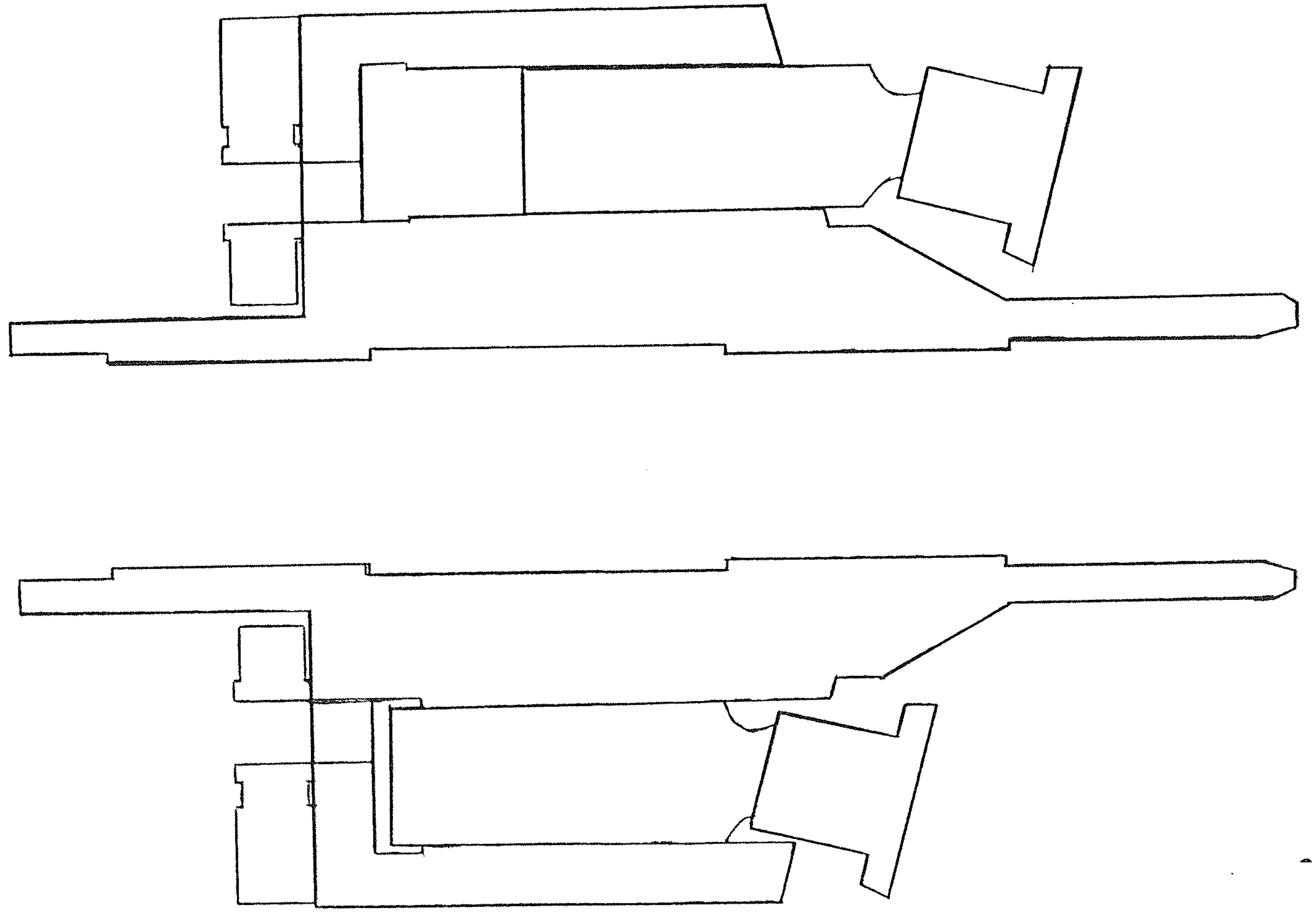
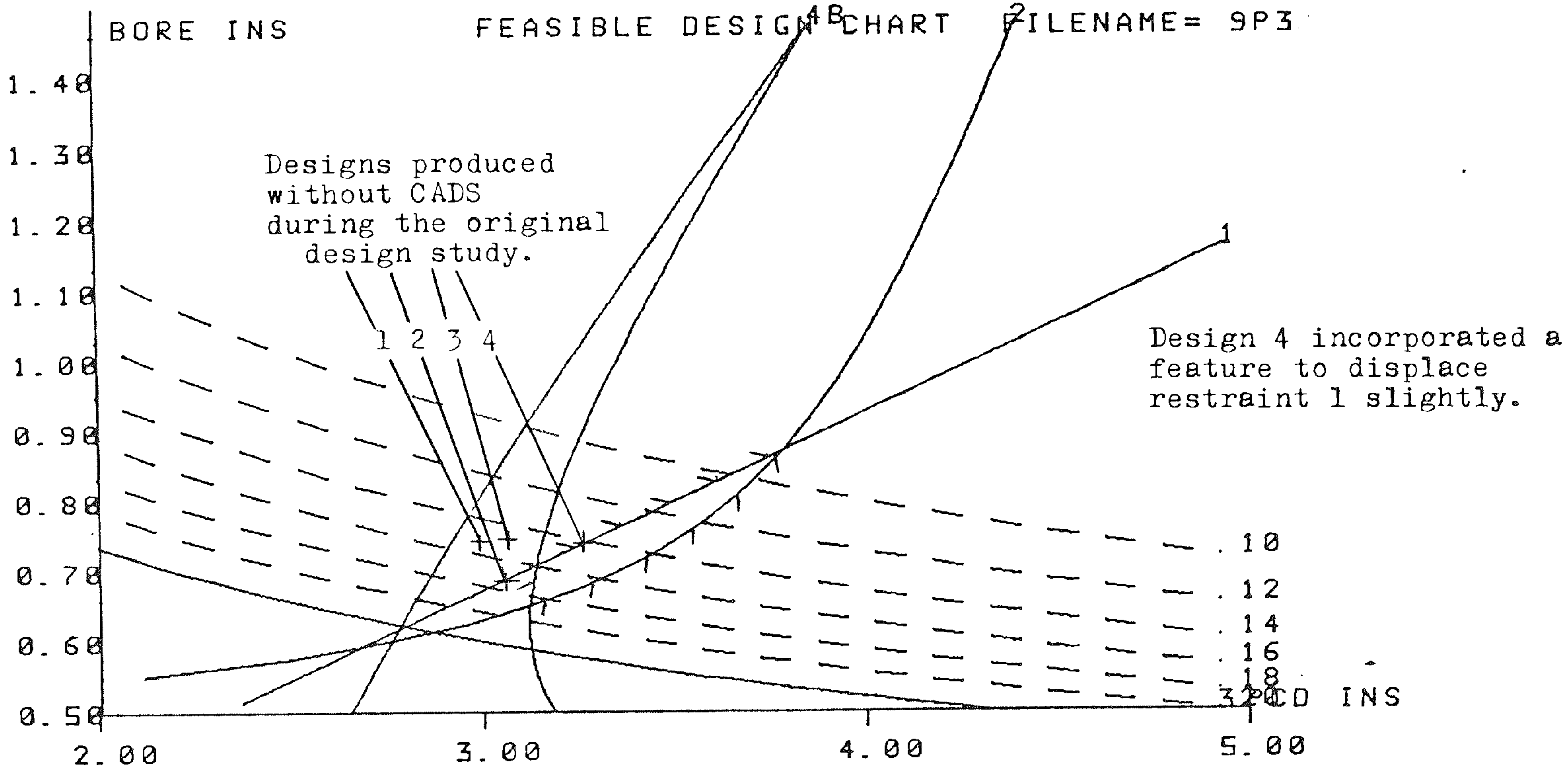


FIG. 10.4 Pump scheme layout produced during the 'user trip'

"re-design" the 3.2 model. Using CADS, a large number of alternatives were rapidly produced during the course of an afternoon. The feasible design charts for seven and nine piston alternatives are shown in fig 10.5. The schemes produced manually, as described in the last section, are represented on these charts. Some of the schemes incorporated design features which displaced one or two of the restraints; this is noted on the charts. These charts show how the feasibility of different alternatives could have been discovered much more rapidly, had CADS been available at the time. As already mentioned, the schemes were produced by junior designers. A more experienced person would have ensured geometric compatibility before presenting the alternative for consideration. Nonetheless, these attempts demonstrate the danger of becoming preoccupied with one design criterion, in this case the head loss criterion (restraint number 2). The benefit of CADS in this situation is that despite any such preoccupied, the remaining restraints remain clear.

Figure 10.6 shows the pump sketch produced by pursuing my own design choice through the design stage of CADS. To proceed this far with the design study, and to continue further to run a performance analysis using CADS took only one day. This compares with four weeks taken for the original user trip. Comparison of figs 10.4 and 10.6 shows that the scheme layouts produced by the two methods were very similar.

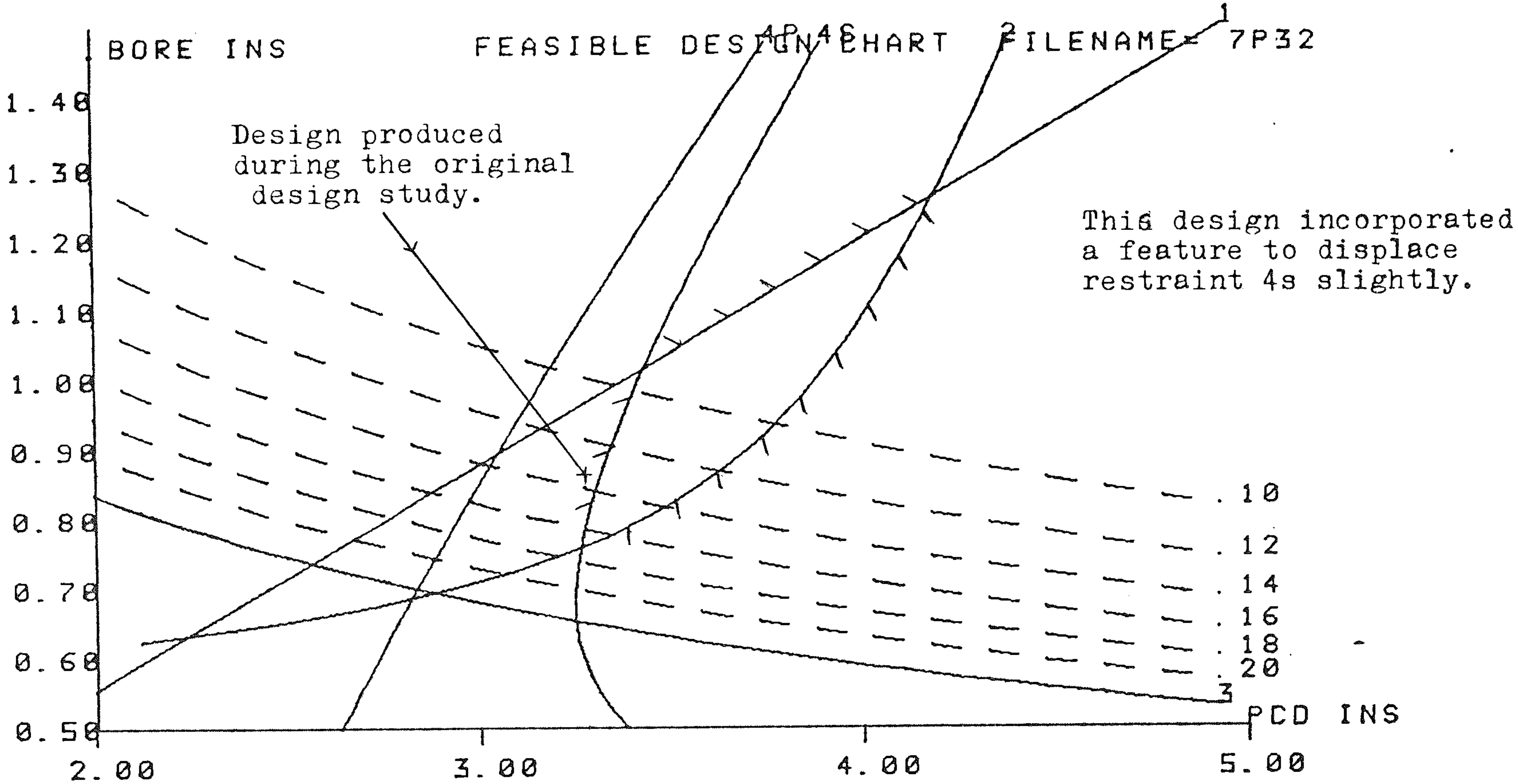
The next exercise undertaken with CADS was to check the final design for this model (the design produced in the



Designs produced
without CADS
during the original
design study.

Design 4 incorporated a
feature to displace
restraint 1 slightly.

FIG. 10.5a Feasible Design chart for the '3.2' model - 9 piston alternative



Design produced
during the original
design study.

This design incorporated
a feature to displace
restraint 4s slightly.

FIG. 10.5b Feasible Design chart for the '3.2' model - 7 piston alternative

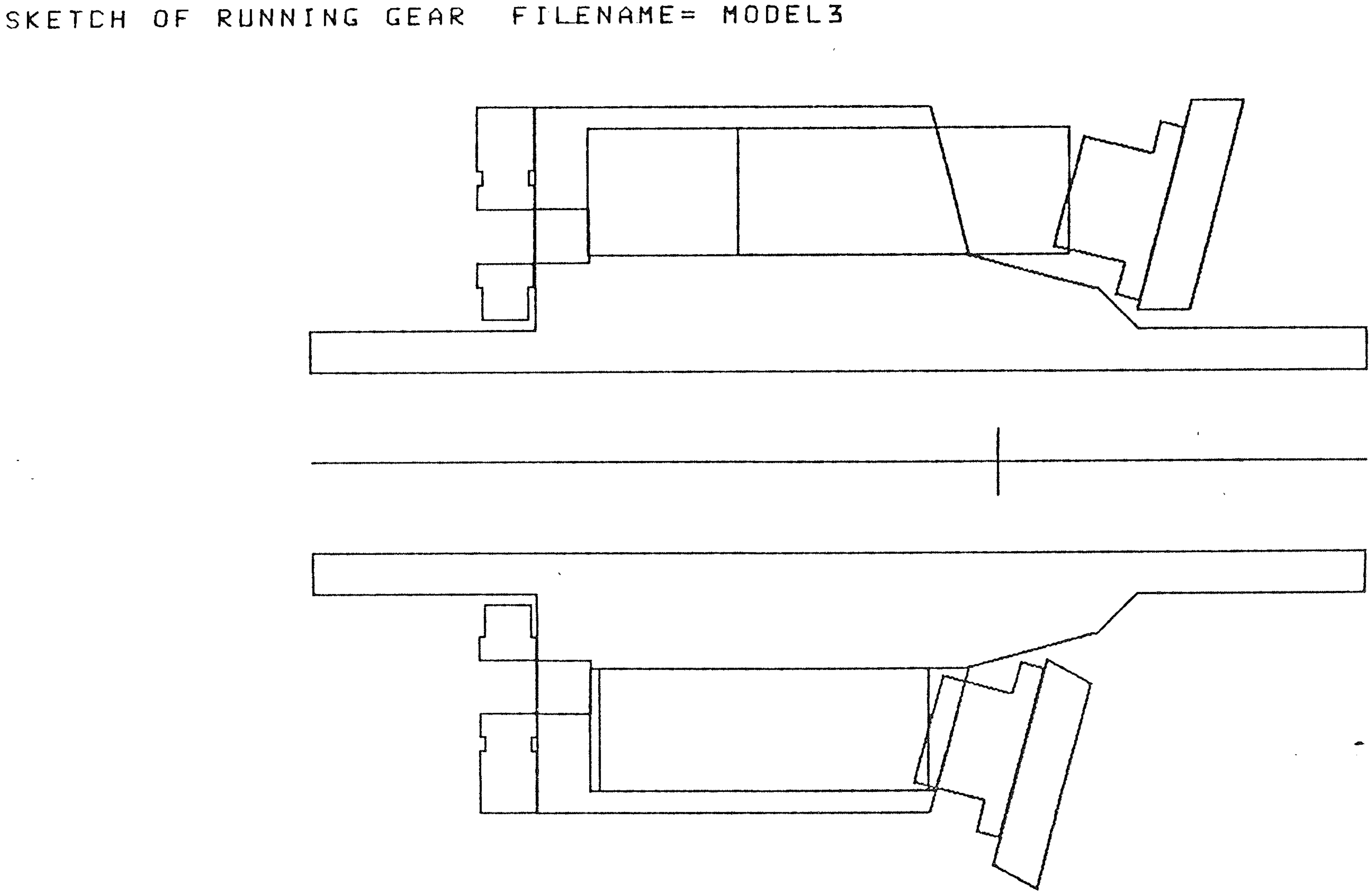


FIG. 10.6 Pump scheme layout produced with CADS for the '3.2' model

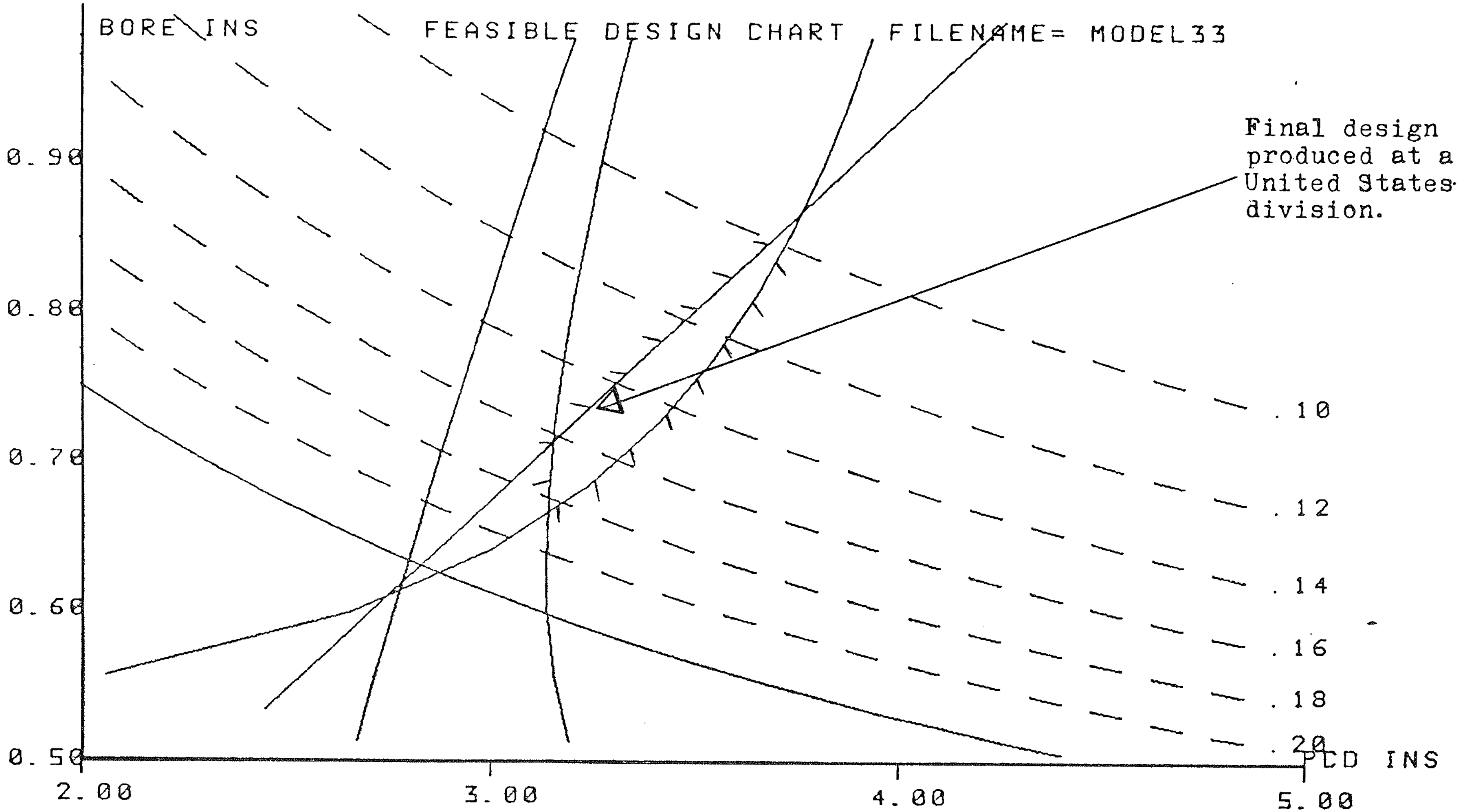
United States). By this time, two years after the initial design attempts, the specification had been altered to "3.3", hence the need for a separate CADS design analysis. This exercise again entailed using CADS in a slightly unorthodox mode; the objective was not to compare and evaluate alternatives, but simply to check the adequacy of the chosen design.

As shown in fig 10.7, the check revealed that the design did not violate any of the design restraints. However, the results of the performance analysis showed that slight modifications to the geometry might be necessary in order to give adequate performance. These findings were reported back to the United States division, where development of the unit is presently continuing.

In addition to the information gained directly from the use of CADS during this exercise, I found that the ease with which the design run could be pursued enabled me, as a designer, to pay more attention to the secondary design aspects not considered by the system, for instance, the shaft detail and the overall tidiness of the layout. This indicated the benefit of CADS in directing the designer's attention towards a more complete awareness of the overall design. This will be discussed further in part IV of the thesis.

10.3. Release to Project Champions

The previous section of this chapter described the way in which I used the design system during the period of limited release. The main purposes were, to check the design software, and to assess the compatibility of the different parts of the



Final design
produced at a
United States
division.

FIG. 10.7 Feasible Design chart for the '3.3' model design system. Some of the results were of immediate benefit to the company, as was the case with the "3.3" design run.

The other users of the design system during this period were the project champions. As described in chapter 9, the purpose of the project champions was to test the system to assess its acceptability for design office use, and also to act as links between the system and the design office staff during this period. In fact I acted as the main link with the design office myself, and the other champions were thus mainly concerned with using the software to uncover any faults.

These two champions did much of the early trouble-shooting for the design system. It was mainly their criticism that led to the first modifications and improvements to the system. They ran the system in earnest, and even set out deliberately to design incredible models to see how CADS would cope.

Numerous trivial inadequacies were discovered. These were mainly due to omissions in programme logic. In this category were the execution errors caused by the user selecting a value outside the sensible range, for instance, entering 813 instead of .813. These were effectively shortcomings in the error handling capacity of the programmes, and although easy to remedy, these might have had profound consequences for inexperienced users, resulting in disillusionment and loss of confidence in the system.

A second class of inadequacy concerned deficiencies in the logic and structure of some programmes. Although thought was given to the optimum programme loop size, as described in part II of the thesis, in some cases the project champions felt that the loops were too large. Some loops consisted of six of more interactive exchanges and although these could be circulated very rapidly, the user found this repetition tedious. Another criticism in the same category was that the coupling between programmes was inefficient as the computer sometimes requested the same piece of information twice in successive programmes.

A list of the criticisms is given in table 10.2. These are categorised to show the broad area of inadequacy.

The basic concept of the design system was not criticised, nor was the worth of any of the individual programmes. On the contrary, the rapidity with which a design could be produced brought commendation for the system.

10.4. Review of Limited Release Period

The previous three sections of this chapter have described the way in which CADS was used before the full release of the system. During this period a number of alterations were made to the software to improve the operation of the system. In particular, a review of outstanding amendments was made shortly before the end of the limited release period, so that at the time of release, all of the major criticisms had been considered and, where necessary, acted upon. In addition to CADS software problems, computer system problems were encountered. Many of these had been foreseen and plans had been made to handle them, nonetheless, they still impeded development during this period.

Halfway through the period, a new policy was implemented for disc allocation. This was done because of problems

ENGINEERING

i/ Load factors fixed at unrealistic values.

ii/ Head loss restraint should be in terms of pressure drop, not velocity change.

INTERACTION

i/ Different pressure units used in two different programmes.

ii/ Design file not erased when design attempt abandoned.

PROGRAMME LOOP SIZE

i/ Some programme loops too large.

ii/ Not all input variables offered for alteration.

PROGRAMME COUPLING

i/ The same input variable sometimes requested twice in successive programmes rather than being transferred directly.

ERROR HANDLING

i/ Programmes occasionally crash when erroneous data entered.

GRAPHICS

i/ Facility for magnifying design charts inadequate.

TABLE 10.2 Problems uncovered by the Project Champions encountered during maintenance sessions and caused by overcrowding of the removable CADS disc. In fact the policy now adopted was that originally planned, (see chapter 7), whereby the CADS disc was used only for programme development, and running versions of the programmes were saved separately on the normal running disc. The reason why this approach had not been adopted from the start, was because of the inconvenience of not being able to maintain the design system while the computer had the normal running disc loaded. However, in view of the problems, the new arrangement had to be adopted and consequently overcrowding was alleviated. There was an additional benefit from this new arrangement, as it meant that a modified programme need not be copied across on to the normal running disc and released, until it had been fully proved. This was found of great benefit when making extensive modifications, such as the addition of new modules.

Despite the difficulties, the phase of limited release went very smoothly. The time taken from the commissioning of the computer to the release of the design system was 4½ months. By this time nearly all of the design software had been switched from the mainframe computer to the minicomputer.

At this stage of the project the situation changed from one of installing software, to one of largely maintaining and updating it according to problems encountered after full release. This phase is described in the next chapter.

11.0. PERIOD OF RELEASE

At the end of the period of limited release, the design system was considered acceptable for use by not only the project champions, but also the other design office staff. Many improvements had been made as a result of the project champions criticisms, and all of the necessary user documentation had been produced according to the plans of chapter 9.

The end of the period of limited release coincided with the start of a feasibility study for a new hydrostatic transmission. The first section of this chapter is a report of the use of CADS during this feasibility study. Following this, in section 11.2, is a description of CADS use in the improvement of an existing transmission. These two activities are shown on the implementation time chart in fig 8.1.

A discussion of the maintenance and modifications required during this period is given in section 11.3. This includes a description of the final proving runs necessary before the design system could be officially released (i.e. before the necessary paperwork could be set up, and the period of rapid programme development formally ended).

The last section of this chapter, section 11.4, is a review of the period of release.

11.2. The design of the new transmission

Work on the feasibility study for the new transmission extended over a period of twelve weeks. During the first eight weeks of this period, CADS was used regularly to assess the feasibility of numerous alternatives. The use of CADS during the first five weeks of this period is summarised in fig 11.1. On this figure the availability of the minicomputer for design work is shown, as are the different design activities that took place.

The chief development engineer of the company was in charge of the project. An engineer and a designer were responsible to him. Fig 11.1 essentially summarises the activities of the designer who carried out most of the CADS work. The use of CADS passed through three phases: familiarisation, an appraisal of an existing design, and real design work on the transmission. These phases are now described.

11.1.1. Familiarisation and the appraisal of an existing design

The familiarisation phase lasted two days. During this time the designer experimented with the early stages of the design system. I was available at all times for advice and comment. Most of the information requested of me was available in the user documentation, but apart from an hour before the start of the familiarisation, during which he read the first user guide (appendix D), the designer preferred to ask rather than read. The questions asked concerned both the use of the system, and details of the theory behind the calculations; all of these points were covered in the documentation. By the end of the first day the designer was familiar with using the design terminal, and very few input mistakes were being made. A few shortcomings of the system were discovered during this period, (see table 11.2). These were by and large corrected during the maintenance sessions on the evening of their discovery.

The familiarisation phase led straight into a phase in

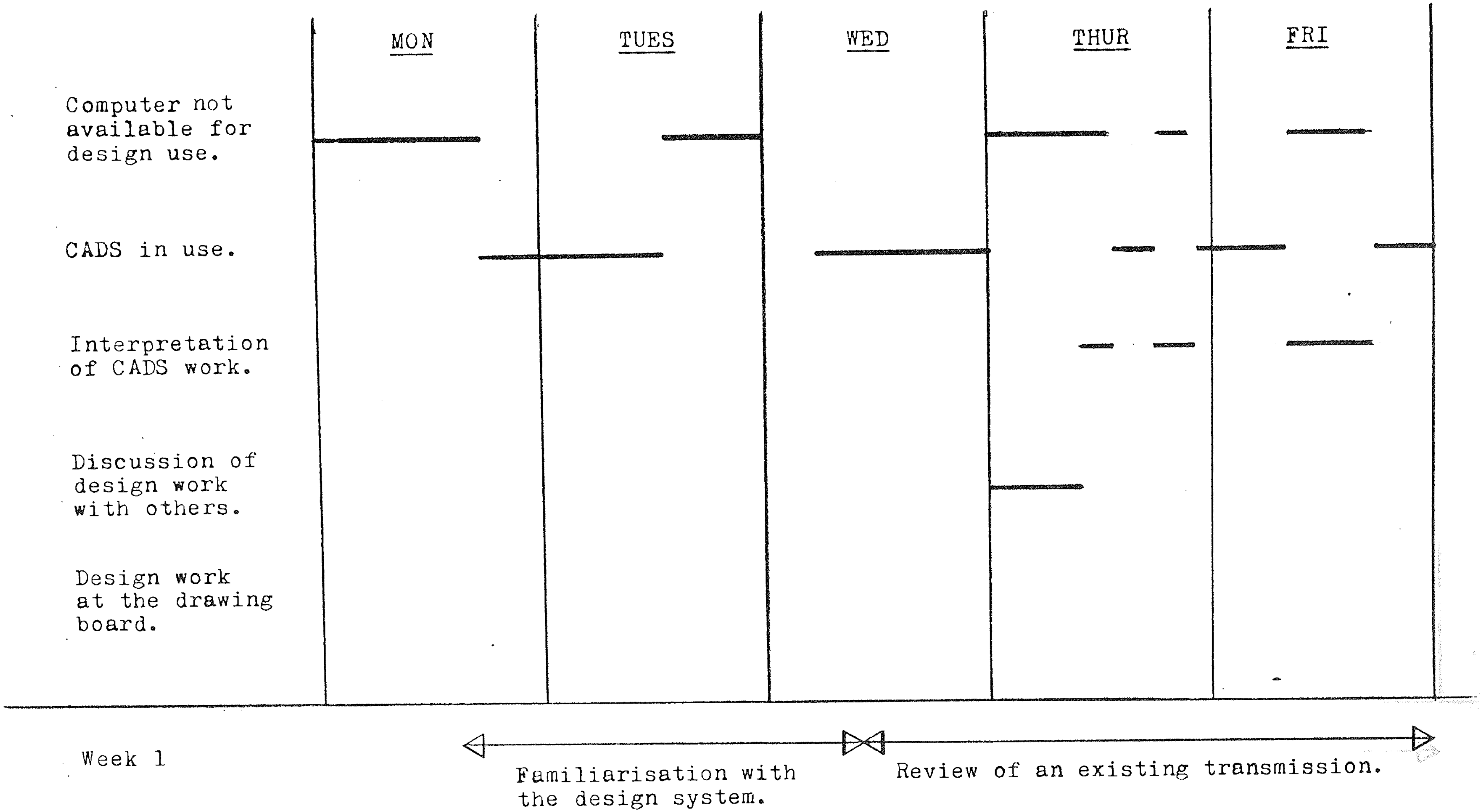


FIG. 11.1 Summary of CADS use for design of the new transmission

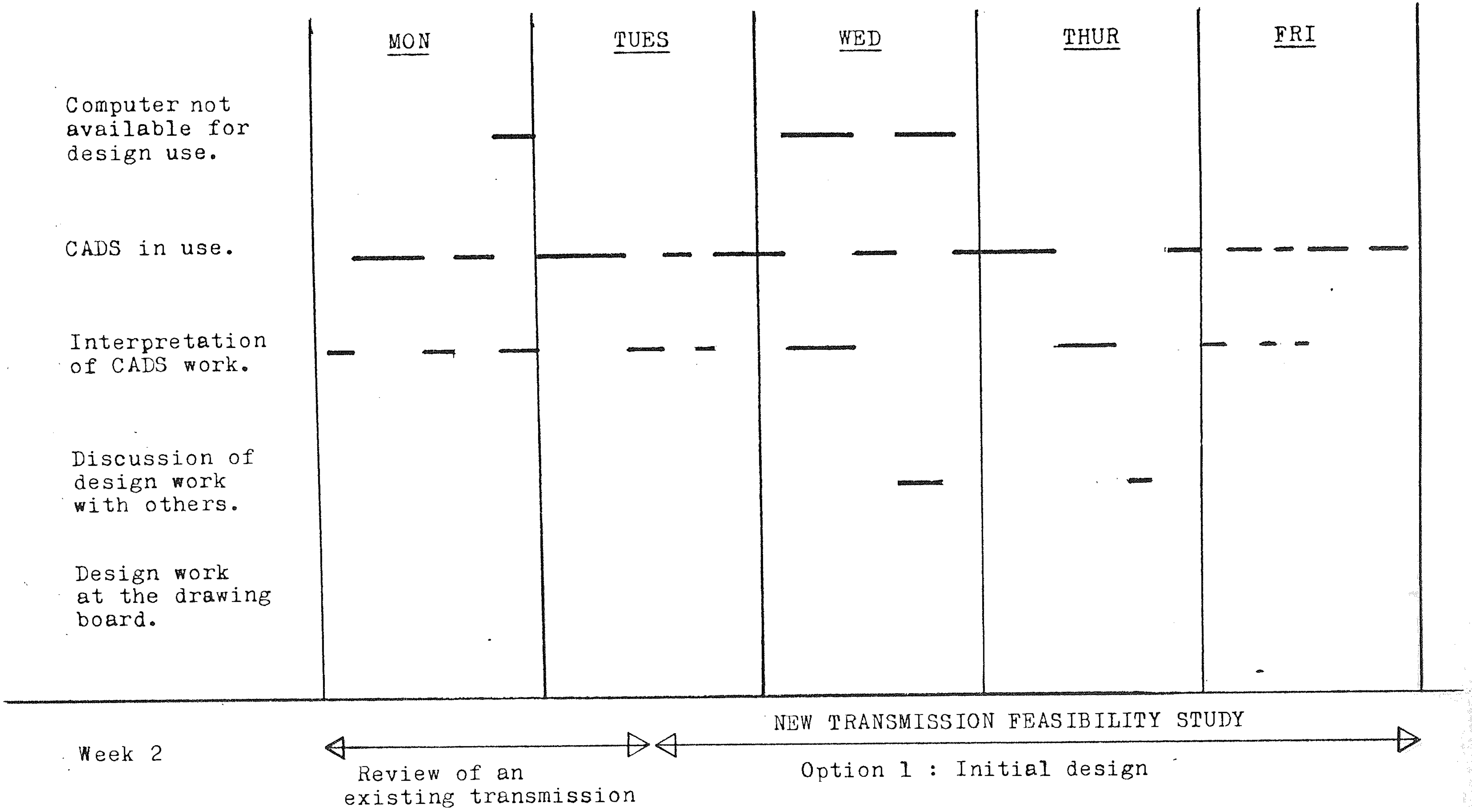


FIG. 11.1 Summary of CADS use for design of the new transmission

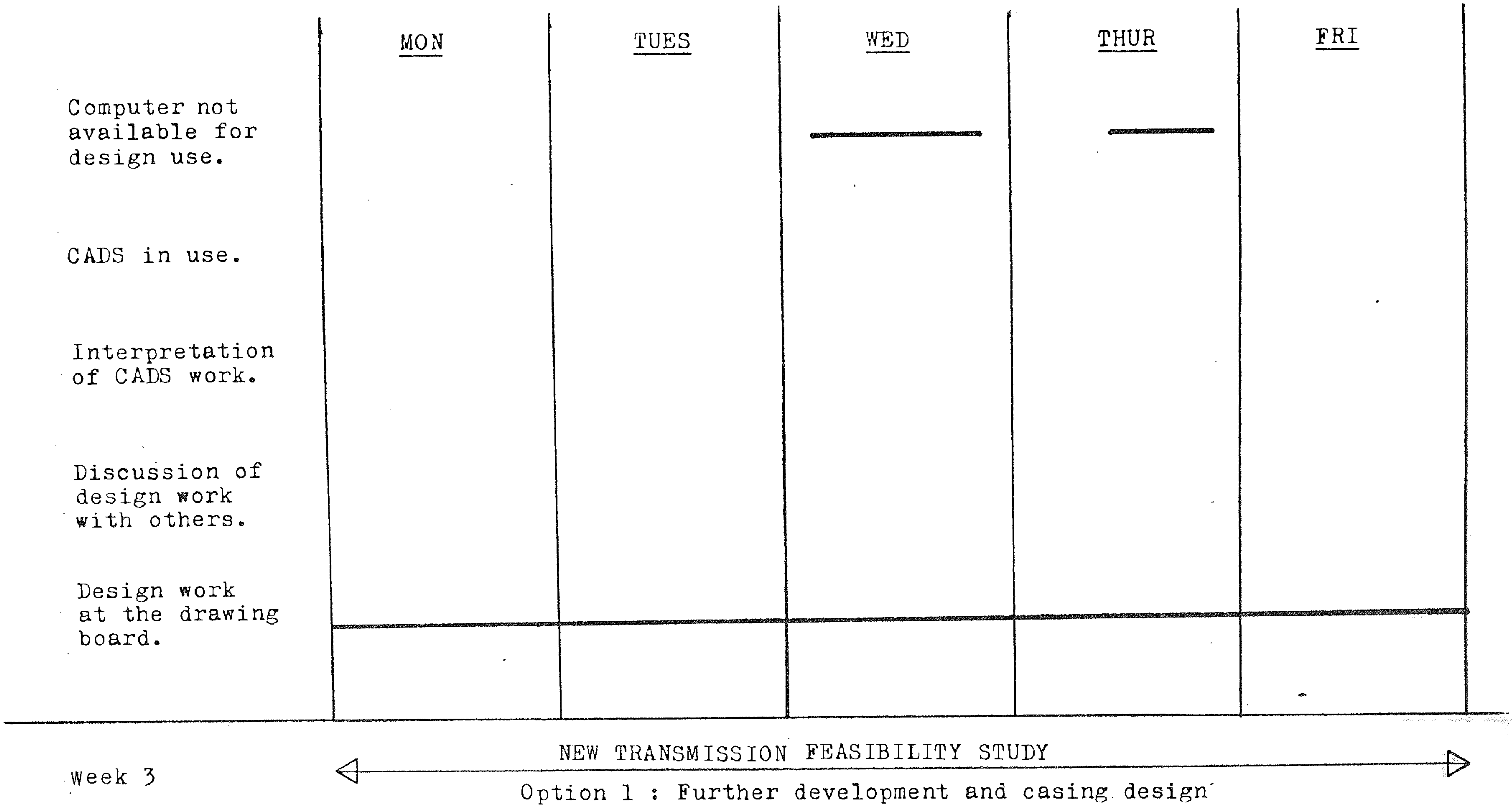


FIG. 11.1 Summary of CADS use for design of the new transmission

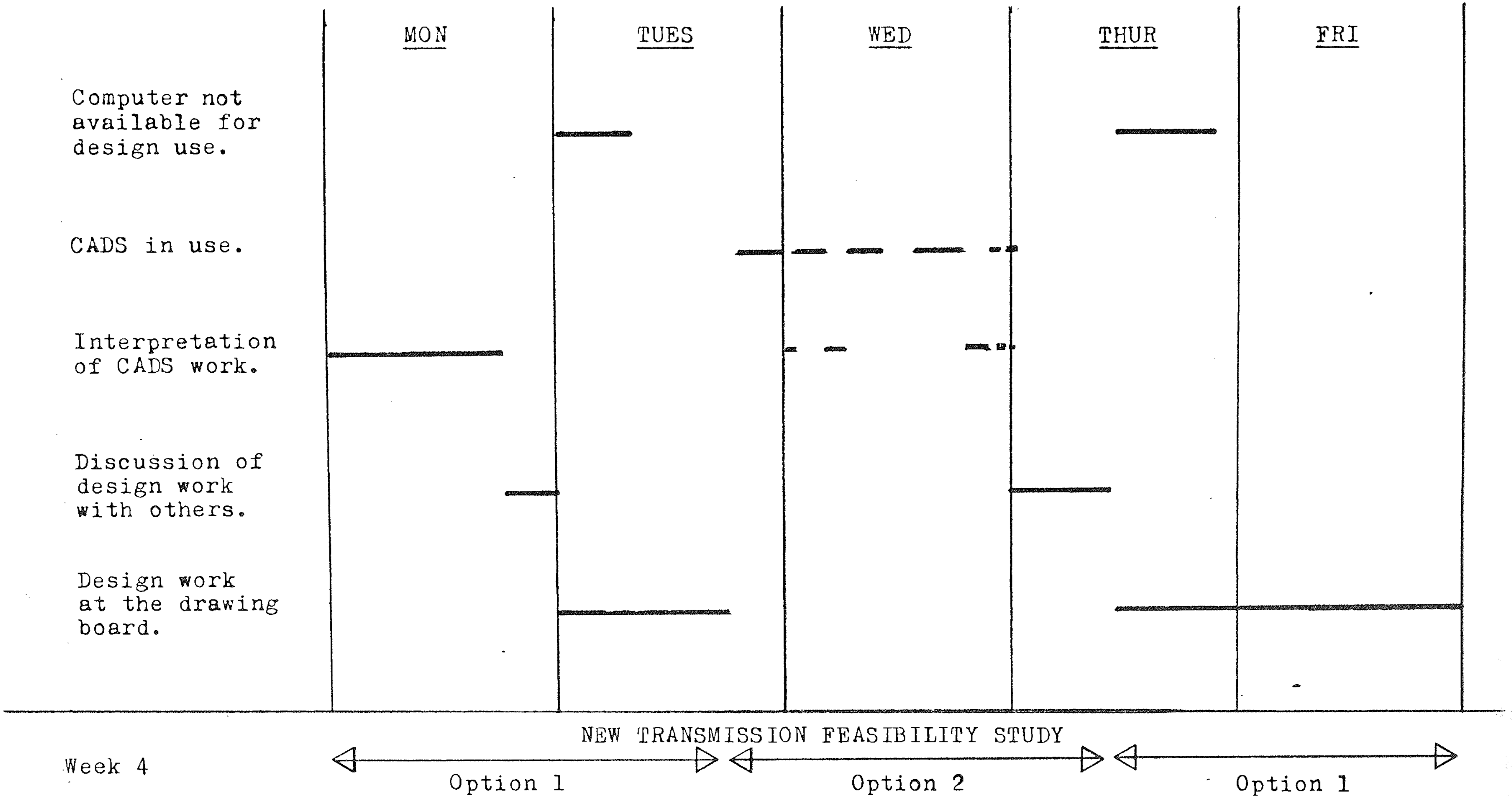


FIG. 11.1 Summary of CADS use for design of the new transmission

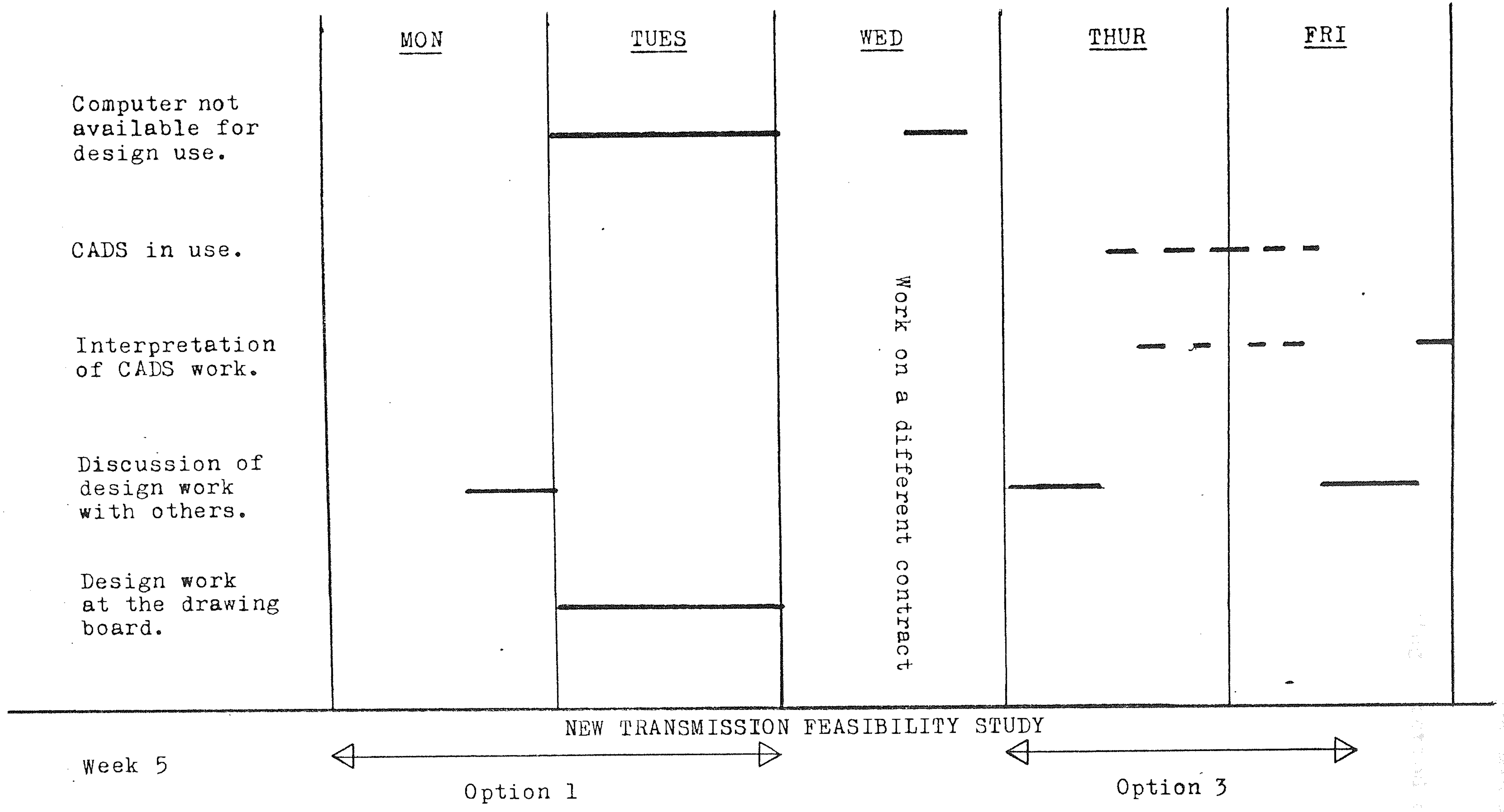


FIG. 11.1 Summary of CADS use for design of the new transmission

which an existing design was reviewed. During a period of four days this design was taken through all the stages of the design suite. This gave the designer a feel for the kind of results produced by the programmes. He could compare these results with his knowledge of the experimental development of the design. One outcome of this exercise was recommendations from the designer, for slight modifications to the detailed design to improve the unit reliability. These modifications were subsequently made.

The results obtained on bearing performance and overall performance were saved for comparison with the results obtained later for the new transmission.

By the end of this period, the designer had used all of the CADS software and was therefore conversant with all the design programmes. The most salient of those problems encountered had been corrected. (The topic of maintenance is discussed fully in section 11.3).

11.1.2. Transmission feasibility study

Figure 11.1 shows how work progressed on the new transmission design after the completion of the existing transmission review. The nature of the new transmission specification resulted in three different approaches being considered by the chief development engineer. Effectively this meant that CADS design runs were necessary for three different pump specifications, (pressure, flow capacity and speed combinations). These are referred to here as options 1-3.

Work began on option 1 half way through the second week of full release. Initially CADS was used a great deal, as shown in fig 11.1. Four alternatives, with different numbers of pistons, were considered for option 1. Each of these was taken through the design system as far as was practical, in effect, until a design inadequacy caused the alternative to be dropped. The CADS work for this option lasted 3½ days. At the end of this time, two alternatives went on for further appraisal and design of suitable casings. At the end of a further week of post-CADS appraisal, one alternative was selected as a favourite for this option.

Next, CADS runs were made for option 2. The total time spent on this option was 1½ days. Three alternatives with different piston numbers were considered. The most promising alternative at the feasibility stage was pursued through the design stage to obtain overall dimensions of the running gear, and finally a performance analysis was run to check the adequacy of this option. As can be seen from fig 11.1, the time spent on option 2 was much less than that spent on option 1. The activity was also much more rapid. This suggests that learning took place. Not only had the designer learnt to use the system more effectively, but also he had learnt how to recognise the most practicable designs at an earlier stage of the CADS runs, by referring back to him experience in previous runs. This latter point was also indicated by the fact that only one alternative for option 2 was taken as far as the performance stage, whereas with option 1, three alternatives were pursued this far.

During the post-CADS appraisal of option 2, the design team decided that it had nothing to commend it over option 1. Furthermore, the shape of option 1 was more immediately suitable for the intended application. For these reasons, work on option 2 was ended and development of option 1 resumed.

Initially only one alternative was considered for the third option. In fact the design team wished to check the adequacy of an existing design of pump, for use in the transmission. The time taken to confirm this was less than one day. Consequently, option 3 was pursued and developed in parallel with option 1. During the subsequent development of option 3, it became necessary to consider further alternatives, with different speed and flow capacity specifications. The ensuing pattern of work in each case followed that of the last two CADS runs, therefore these will not be described further.

At the end of the feasibility study, two clear alternatives had been adopted and were submitted for the customer's approval. One of these arose out of option 1, the other out of option 3. This formed a natural break for CADS work on the design. Work was unlikely to be resumed until a clear alternative had been accepted by the customer. At this time design would begin in earnest and CADS would again be used to help detail the proposed design.

11.1.3. Appraisal of the feasibility study

The start of the release period went very smoothly. The training of users went largely as planned, with much supervision necessary during the familiarisation phase. Within a few days useful results were being obtained from the work. One implicit benefit observed during the course of the work, was the designer's growing awareness of the factors which limit the design of pumps. This was reflected in both the learning that took place and the evaluation which the designer made on the CADS work as it progressed. For instance the designer rapidly became aware of the consequences of designing close to a particular constraint of the feasible design chart. He also learnt how to "manipulate" the performance chart by making modifications to the design. These skills not only improved his efficiency with the design system, but also resulted in a better understanding of the pumps.

The use of CADS blended well with the designer's other duties. This was indicated by the ease with which he moved from CADS work to post-CADS development as shown in fig. 11.1.

Without CADS it would have been possible to consider only a few of the alternatives pursued for the feasibility study. As mentioned in chapter 10, production of a scheme layout for the "3.2" model took a junior designer four weeks. Even an experienced designer would take at least two weeks to produce such a scheme. This was confirmed by the time taken to draught a casing for the option 1 running gear produced with CADS. In contrast, the time taken to produce a scheme using the new design system was, on average, half a day.

The shortcomings encountered during the feasibility study are reported fully in section 11.3. The total time lost due to CADS software errors (resulting in work having to be repeated) did not exceed half a day. Overall, CADS was found very useful in the feasibility study and was quickly accepted as a design tool.

11.2. Improvement of an Existing Transmission

Shortly after the end of the feasibility study described in the last section, a further exercise was undertaken with the aid of CADS. This was a review of an existing transmission with a view to improving its reliability.

As an aid to development, CADS helped in three ways:

(i) By enabling identification of the factors influencing unit reliability. (This was done by correlating programme results with experience).

(ii) By enabling investigation of ways (whether feasible or not) of improving the reliability.

(iii) By enabling evaluation of practical improvement proposals made by designers.

The attempts to correlate the experimental results with programme predictions were only partially successful. The performance programme did correctly predict the general mode in which units would fail, but it was less successful in predicting correctly the performance of individual units, for instance, why one unit should run better than another. The conclusion was that variables not considered by the programme were contributing to the experimental results. Nonetheless, the general correlation was sufficient to inspire confidence in the use of the programme for the other two purposes listed above.

The CADS programmes were next used to discover mechanisms that might lead to an improvement in reliability. A large number of mechanisms were investigated over a period of two days. These might all have been feasible in a complete re-design, but certainly were not all feasible as design modifications. They were, however, all noted and used as an aid to the conception of realistic design modifications.

The final use of CADS, and the phase that took up most of the period, was the evaluation of real design alternatives suggested by designers. Some of these had been indicated by the previous CADS runs. In total, 14 distinct modifications were suggested. (This abundance of ideas confirms the premise made in chapter 3, that there was no shortage of creativity within the company). A summary of the ideas and their development is given in table 11.1. As these modifications are confidential, they cannot be described specifically, but they are split into four categories: modifications to the portplate, cylinder block, bearings and material changes.

Each idea was first evaluated, if possible using the CADS software, before a decision was made whether or not to develop it. Promising ideas were then drawn at the board and, if they still looked attractive, they were produced and tested. Of the 14 ideas, 7 could be evaluated effectively using CADS. Eventually, a combination of 3 of these modifications were made to the design. These contributed to give a substantial improvement in reliability.

Of the eight engineers involved in the review, five used CADS personally during the investigation. Others were involved in evaluating the results and arranging the necessary development of ideas. A few problems of use were encountered during this period, but these were quickly overcome and did not impede progress. Four different CADS programmes were used during the review. These were:

(i) The performance programme (used almost continuously to assess alternatives).

(ii) The flexibility analysis package (to

	IDEA	Could idea be evaluated using CADS?	Was idea developed further?	Produced and tested?
1	Portplate modifications	Y	Y	N
2		Y	Y	N
3		Y	Y	Y
4		N	N	N
5		Y	Y	Y
6		Y	Y	Y
7		N	N	N
8		N	Y	N
9		N	Y	N
10	Cylinder block modifications	Y	Y	N
11		N	Y	Y
12	Materials modifications	N	Y	Y
13		N	Y	Y
14	Journal bearing modification	Y	Y	Y

TABLE 11.1 Ideas for improving the performance of an existing transmission

calculate the flexibility of modified cylinder blocks).

(iii) The portplate design programme (to indicate the adequacy of modified portplates).

(iv) The bearing design package (to assess the effect of other modifications to the portplate and bearings).

The overall investigation extended over 6-8 weeks. At the end of this time the final modifications were being tested.

11.3. Maintenance and Modifications

11.3.1. Maintenance during the Release period

During the release period efforts were made to keep the design system up-to-date and so problems that arose during the CADS work were rectified the same evening. Table 11.2 shows a number of faults that arose during the release period and indicates the promptness with which they were dealt. The problems which are classified "U" (urgent) are those that had to be corrected before CADS work could continue satisfactorily. Table 11.2 shows that despite efforts to remove all problems by the use of project champions, when the system was used in earnest by a new user, numerous shortcomings were uncovered. The time taken to amend each problem is also indicated in the table. Most were dealt with in less than an hour and were therefore remedied before the next design session. These, by and large, were CADS software errors and could therefore be remedied without recourse to computer system maintenance.

A few difficulties were caused by computer system

No.	PROBLEM OR FAULT	Type	DISCOVERED		AMENDED	
			How	When	When	Time taken
1.	Difficulty in reading design choice off Feasible Design chart.	U	Early runs with the feasibility programme.	7/11/77 1630hrs	1830hrs	30 mins
2.	Over pessimistic piston neck design restraint.	U	Feasibility programme run for an existing model.	7/11/77 1640	1900	30 mins
3.	Flexibility package fails when metric units used.	U	First run of flexibility package.	9/11/77 1600	1800	1 hr
4.	Contamination of the input data for the performance programme.	U	First repeated use of the programme.	9/11/77 1400	1900	45 mins
5.	Units of the performance programme inconsistent.	U	First repeated use of the programme.	"	"	"
6.	Hard copy option not functioning.	S,U	During a normal design run. Fault created at last maintenance session.	10/11/77 1725	1800	3½hrs
7.	Inconsistency in the load factor selection in the feasibility programme.		Sometimes load factor assumed, not asked for.	10/11/77 1700	2130	20 mins

TABLE 11.2 Problems encountered during CADS use

No.	PROBLEM OR FAULT	Type	DISCOVERED		AMENDED	
			How	When	When	Time taken
8.	Better definition of the cylinder block O/D required in the DESIGN programme.		Suggestion from the designer after use of the programme.	10/11/77 1710	11/11/77 1545	30 mins
9.	Information retrieval programme lists incorrect value for swash angle.		Listed value checked against the sketch produced.	10/11/77 1715	''	5 mins
10.	Hard copy arrangements for the performance programme differ from the convention.		Confusion experienced by the designer when using the programme.	14/11/77 1000	15/11/77 1815	30 mins
11.	Inappropriate stress analysis used for cylinder block O/D calculation.		Designer not content with value suggested by the programme.	15/11/77 1500	1800	15 mins
12.	Option 2 unit too large to be plotted on the design terminal or plotter.	U	First feasibility runs for the option 2 unit.	16/11/77 1700	1800	1½hrs
13.	Frustration caused by the material selection procedure.	G	Use of the feasibility programme as a checking tool.	16/11/77 1400	Currently under review.	
14.	Design file name not marked on the hard copies.		Designer having to remember to label the hard copies himself.	18/11/77 1600	25/11/77 1430	3 hrs

TABLE 11.2 Problems encountered during CADS use

No.	PROBLEM OR FAULT	Type	DISCOVERED		AMENDED	
			How	When	When	Time taken
15.	No dimension lines on the sketch of the running gear.		Designer having to spend time dimensioning the sketches produced.	18/11/77 1000	Not planned at present.	
16.	Problems due to the discreteness of the graphics curves when design charts expanded.		Difficulty in interpreting an expanded Feasible Design chart.	18/11/77 1200	Not planned at present.	
17.	Request from the designer to improve the loop structure around the bearing design sections.		Delays caused by having to "guess" what comes later in these sections.	17/11/77 1600	18/11/77 0900	30 mins
18.	Request from the designer to see .99 eccentricities on the performance chart.	S	Problems of assessing the performance under heavy loading conditions.	17/11/77 1000	Attempt abandoned after problems with core and disc limits.	
19.	Request from the designer to improve the coupling between stages I and II.		Occasional inconvenience with the original method.	30/11/77	7/12/77	2 hrs
20.	Request from the designer for a hard copy of the design terminal interaction.	G	Problem in having to remember certain features of the design runs.	30/11/77	Currently under review.	

TABLE 11.2 Problems encountered during CADS use

problems. These were mainly teething troubles, some of them caused by the company's lack of familiarity with minicomputers. These problems, which were generally more difficult to amend, are denoted "S" (systems) in the table.

A third category of problem denoted "G", required the development of further general purpose software. This was the case with problem no. 20, (the request for hard copies of design runs). This kind of difficulty affected all progamming and necessitated not only the writing of extra software, but also extensive editing of all programmes concerned. For this reason this category of maintenance was left until the end of the period of release when demand for CADS runs fell off.

In parallel with the modifications to the programmes, the documentation had to be updated. This was achieved quickly and simply by making modifications to the master copies of the user guides, which were kept adjacent to the design terminal.

11.3.2. Maintenance at end of release period

At the end of the release period, the CADS software was again tested by a project champion, this time with a view to discovering the amendments necessary prior to official release. The documentation was first checked, not only the user guides, but also the programme descriptions containing details of the programme theory and structure.

During the programme runs, which followed, the project champion spoke his thoughts aloud. This enabled me to record his specific criticisms, and also to assess how well he was now able to cope with the programme interaction, (many modifications had been made since the period of limited release). No serious problems were encountered. The champion felt that the interaction was clear throughout, however, he did criticise the format used to present the dialogue on the design terminal, and suggested that this be improved before official release.

Finally, programme code listings were checked to ensure that they had been written according to the standards set out.

After correction of minor faults, the software was considered ready for official release. The programme code listings and programme descriptions were collected and saved in a programmes issue file. The software was then copied to a separate user number reserved for officially released programmes. Once the programmes had been officially released, maintenance procedures were formalised to bring them to their present state.

Although experimental software modifications can still be tried out on the CADS development disc, no alterations are allowed to the running version until these have been fully proved and the necessary programme change procedure has been followed. The change procedure entails completion of a document explaining: the need or reason for the change, the exact nature of the change, and the effects that this has on programme operation. After each change is made, the corresponding document is saved in the programme's issue file. In this way programme users can quickly discover the current state of any programme.

Another aspect of maintenance concerns the way in which user's comments are reported to the programme writers. For this project the method adopted entails the use of a "COMMENTS" book which is kept by the design terminal and in which any user may record his problems or suggestions. By checking the contents of this book regularly, say once a month, a programme writer can discover how successful his software is, and arrange to deal with any points requiring attention.

11.4. Appraisal of release period.

The period of release lasted five months during which time CADS was used to aid both design and development work. When interviewed prior to release of the system, potential users made a number of predictions about the success of CADS. These are recorded in table 11.3 along with the actual outcome.

The main fears were that CADS would inhibit the designer or take control away from him, possibly by removing the opportunities for initiative or slowing the pace of the work. These fears were not substantiated, and the designer rapidly learnt to use CADS as an effective design aid. Apart from occasional delays of up to thirty seconds caused by long internal iterations in the analysis packages, the pace of CADS runs was determined by the designer. In the case of both the new transmission design and the existing transmission review, the duration of the exercise was determined by the time taken to develop the work produced using CADS. This was indicated in fig 11.1.

The usefulness predicted by users was borne out by the work already described. In addition to this the system clearly demonstrated to the user some of the fundamental criteria affecting pump design and performance.

PROBLEMS PREDICTED BY THE USERS	ACTUAL PROBLEMS ENCOUNTERED
i) Difficulty of producing effective documentation.	i) Progress with design studies dependent on the evaluation and discussion phases, (i.e. maximum time saving influenced by the time taken for these activities.)
ii) Possibility of inadequacies ruling the system out of design studies, (due to the time required for maintenance).	ii) Progress also limited by the time taken to carry out the non-aided creative aspects of the design work, (e.g. casing design).
iii) Problems of learning the new skills required, e.g. computing.	iii) Mental fatigue caused by designers tackling many alternatives at once.
USEFULNESS PREDICTED BY THE USERS	ACTUAL USEFULNESS OF THE SYSTEM
Useful for:	Useful for:
i) Highlighting constraints and suggesting how these might be overcome.	i) Quickly eliminating impractical alternatives.
ii) Enabling performance analyses of existing units.	ii) Quickly producing numerous scheme layouts for visual comparison.
iii) Facilitating rapid comparison of design alternatives.	iii) Teaching designers the way in which the various design factors constrain a design.
	iv) Reviewing or checking existing designs.
	v) Explaining experimental results or failures.
This information was obtained during interviews with D.O. staff prior to release of the system.	This information was inferred from the way in which the system was used after release.

TABLE 11.3 Predictions made by design system users

The degree to which the designer retained control of the design work, using the new system, was shown during the new transmission design. There were vast differences between the schemes proposed by the sponsoring company, and those proposed by a competitor for the same contract. The competitor's design team had adopted a different specification and had made different principal decisions during the design work. For comparison only, suitably modified criteria were used in a subsequent CADS run. The result was a scheme much closer to the competitors.

Halfway through the release period, after a request from the design team, a new module was devised for the feasibility and design stages of CADS, in order to cater for a possible new design of swash plate. The geometric problems associated with the new design were three dimensional and difficult to consider without detailed draughting. Work on the new module was carried out in parallel with the system maintenance and extended over a period of two weeks. The actual time spent on the module was eight hours, of which four were spent deriving the necessary equations defining the geometry and operation of the new arrangement. No problems were encountered in producing this module and design work was not interrupted. Although the modification was straightforward, the ease of update showed promise for the future of the design system. Subsequently, another programme module was updated, this time belonging to the performance programme. Again the modification was quickly accomplished and no problems were encountered.

Returning now to the recommendations set out in chapter 2 for job satisfaction,we see that in most respects, the system produced is satisfactory. As the work on the new transmission design progressed, the designer gained a sense of achievement and certainly an interest in the work itself. This was doubtless helped by the knowledge that he was learning from the experience. The style of interaction incorporated into the system satisfied the main psychological objectives by enabling a flexible, informal flow of information between the designer and the computer.

The only slight problem was that of fatigue encountered early on when CADS was being used extensively. This problem was eventually solved when a terminal booking system was introduced and the maximum continuous period of terminal use was limited to two hours.

PART IV

12. EVALUATION OF THE PROJECT

12.1. Satisfaction of objectives.

12.2. Benefit for the sponsoring company.

12.3. Discussion.

12.4. Recapitulation.

12.0. EVALUATION OF THE PROJECT

In this chapter an evaluation of the project is given. Section 12.1 first reflects on how adequately the original project objectives have been satisfied. This is followed by a section in which the benefit for the sponsoring company is estimated. In particular, the benefits of the new system over the original system are expounded. Section 12.3 draws conclusions from the experience gained and suggests how this might help the sponsoring company or other companies in future work. The final section is a recapitulation of the achievements of the project.

12.1. Satisfaction of objectives

12.1.1. Objectives satisfied to date

In chapter 3 the primary objective for the company was defined. This was then developed into four specific objectives for the project and a set of basic requirements which any proposed solution had to satisfy. These are all listed in fig. 12.1. The work reported in parts II and III of this thesis has resulted in all of the specific objectives and requirements being satisfied. A systematic design system has been devised, implemented and used to aid both design and development work. The results obtained show that the new system can be used to produce a large number of alternatives very rapidly, in a form that can be quickly evaluated by the designer.

The philosophy expounded in chapter 6, concerned with the production of effective interactive software, adequately satisfies the second project objective: to produce an effective interface between the design system and the designer.

The system has already been operated by six design office

PRIMARY PROJECT OBJECTIVE

To improve the company's design method so as to reduce the combined design and development lead time.

SPECIFIC PROJECT OBJECTIVES

i) To devise logical and systematic procedures for designing axial piston pumps with more certainty.

ii) To find the best way of presenting these to the designer.

iii) To implement these procedures in the existing design office environment.

iv) To monitor the use of the design procedures and to subsequently evaluate them.

SOLUTION REQUIREMENTS

i) The procedures had to be easy to understand and use, and require little specialised knowledge on the part of the designer.

ii) They had to be pleasant to use so that a designer would be motivated to use them.

iii) They had to be versatile enough to cope with deviations from normal design practice.

iv) Updating and other improvements had to be easy to implement.

v) The procedures had to make full use of scientific research, and experience gained through development and testing.

FIG. 12.1 Objectives of the Project

staff. All of these were able to use the system unsupervised after very short training sessions (less than 30 minutes per programme). The responses of all users have been favourable; all felt that the benefit of the system outweighed the minor difficulties encountered during the release periods.

The versatility of the system was demonstrated by the ease with which it could be used for either producing new designs or checking and developing existing designs. The modular structure used for the system meant that it could also be maintained and updated very easily. This enabled the system to be kept operational throughout the release periods.

12.1.2. Satisfaction of the primary objective

As shown in fig 12.1, the primary objective for the company was to reduce the combined design and development lead time associated with production of a new model. The method adopted was to devise procedures whereby a new model produced would require fewer post-prototype modifications. Although the design procedures developed certainly result in a more rapid and systematic design method, as the design system has only been generally available for four months, it is not possible to say with certainty whether the combined design and development time will be reduced. Instead, we will have to make an estimate based on a comparison between the progress made on the new transmission contract, described in chapter 11, and work on previous contracts undertaken by the company. The opinions of the design office staff and management must feature largely in this estimate.

A study of previous contracts of the company revealed that the development period generally passes through three phases. The first phase proceeds as far as the prototype production. After this, is the phase of assembly and initial commissioning tests. The final phase entails testing under a full range of operating conditions. During any of these phases problems may result in design modifications and consequent modification of the prototype.

On previous contracts the elapsed time from completion of first detail drawings to the first successful test of a prototype had been about nine months. The average time taken to accomplish one modification to the prototype (the lead time on prototype modifications) was typically three weeks. The company's design team estimated that in the first two phases of development, three or so modifications would be saved by having used CADS at the design stage. This is equivalent to a saving of nine weeks.

During the design work, CADS had enabled the designer not only to assess the scope for modification but also to make performance analyses for a full range of operating conditions. This, the design team felt, would lead to further time being saved during the third phase of development as not only would the unit be more likely to satisfy the performance criteria, but also minor modifications would be more easily accommodated. The experience with CADS gained during the existing transmission review (section 11.2) suggested further, that those modifications that were necessary might be more satisfactorily accomplished now that CADS was available.

Overall time savings during the third development phase are difficult to assess, especially as the length of this phase varies considerably between contracts. However, a figure of 10% was predicted by the design team. This would represent a saving of eleven weeks on a typical contract.

In addition to these savings, there is the saving on the initial design. Experience on the new transmission contract suggested that a final reduction of five weeks was likely on this design phase. The overall situation is now summarised in the table below.

	Original Duration (weeks)	Estimated saving (weeks)	Duration after savings (weeks)
Design phase	36	5	31
First & second phases of development	48	9	39
Third phase of Development	108	11	97
Total	192	25	167

Estimated time saving = 13%

TABLE 12.1 Estimated saving on the design and development lead time

Admittedly, these estimates are fairly crude, but they do indicate the savings that are expected in the combined design and development time. These are somewhat lower than those set out in the original objectives, but as will be shown in the next section, the savings still represent a net cost benefit to the company. As the design system is developed in the future, these savings should increase.

12.2. Benefit for the sponsoring company

The objectives of the project were primarily intended to benefit the company. There were, of course, advantages for other parties such as the designer and the customers, but these, too, should reflect favourably on the company through improved labour relations and an enhanced reputation. In this section we divide the benefits into several categories, beginning with a justification on a cost basis alone.

12.2.1. Cost Evaluation

Figure 12.2 shows the savings expected on the cost of the design and development period by using the new design system. It is assumed that the capital cost of the design system was borrowed at 15% and will be repaid over a period of 5 years (the nominal life of the computer system)*. To simplify the analysis it is also assumed that the costs of training and maintenance for the new system are the same as for the original system.

The estimate of 10 man-weeks saving on the design phase is based on the design study for the new transmission. This estimate was endorsed by the technical manager. As expected, the main savings ensue from the development period. The figures of Table 12.1 show that savings of 13% are expected in this phase. These savings will result in a net cost benefit to the company.

In addition to this straightforward analysis there are further benefits of reduced design and development lead times.

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* Details of actual financial arrangements are naturally confidential.

Capital cost of the minicomputer attributed to the design system	£20000		
Cost of developing the design system.	£15000		
	35000		
Assume this money is borrowed at 15% to be repaid over 5 years, (estimated life of the minicomputer.			
Annual repayment		10400	
Design time saving assuming 1 design feasibility study every two years: $\frac{2\text{men} \times 5\text{weeks} \times 35\text{hr/wk} \times £12\text{/hr}}{2\text{yrs}}$			2100
Cost benifit of 13% reduction in development time,			30000
			32100

Estimated net annual saving = £22000 approx

* These figures constitute an estimate only and are not intended to indicate the company's actual financial circumstances or policies.

FIG. 12.2 Cost evaluation of the project

The reduced design time means that tenders for customers can be produced more rapidly. The reduced development times means that more markets are opened as earliest production dates can be brought forward. Both of these factors increase the possibility of order capture. As a single order may be worth £¼m per year in profit, this is clearly of importance in a cost evaluation. However, as the feasibility of order capture depends on several other factors (e.g. the company's production capacity) no attempt will be made to quantify this aspect.

12.2.2. Benefit for the designer

According to the comments of users, CADS was pleasant and interesting to use. Essentially, two tedious activities present in the original design procedures had been removed. These were: the necessity of making repeatedly a large number of calculations, and also the need to make scale drawings of many alternative design schemes and their components. This latter activity is distinguished from detailed draughting, which still had to be carried out once firm decisions regarding layout had been made.

CADS offered the designer more scope for initiative than the original inflexible design guide, but at the same time effectively warned him of the consequences of his ideas. He thus became more confident to explore new possibilities. The rapidity and simplicity of the new system encouraged the designers to use it often and helped prevent boredom.

Dependence on the designer's memory, implicit in the old system, was reduced with CADS, however, this advantage was partly offset by the tendency to consider more design alternatives. The need to search for data was also reduced; this benefit will become more apparent as the information retrieval system is developed.

The availability of the common knowledge implicit in CADS meant that the designer could more confidently attempt problems that he might otherwise have thought beyond his ability, knowing that in turn his extra experience could be fed back into the system for others to use.

To summarise, the overall effect of CADS on the designer was both enabling and provoking: the system not only enabled him to carry out new and interesting work, but also encouraged him to do so.

12.2.3. System flexibility

As suggested in the last section, the original design procedures were inflexible. They were also vulnerable to deterioration through turnover of staff and consequent loss of experience. The development of CADS helped to improve this situation. The arrangement of the software was designed to warn rather than instruct, thus the real decision making was left with the user. Inevitably, a large quantity of engineering knowledge was stored permanently in the computer. This could be added to at any time by updating the system.

In chapter 11, an updating session was briefly described. This indicated the effectiveness of the modular structure for ease of maintenance. This modular structure also enabled CADS to be used as either a number of stand-alone tools or an overall system, another manifestation of the flexibility which resulted in its being used with equal success in both design and development work. This was demonstrated by the work done on both the new transmission and the existing transmission review.

A clear benefit of CADS over the original design method was indicated during the design of the new transmission by the large number of alternatives considered. This allowed a degree of optimisation that would have taken much longer to achieve using the original method.

The full flexibility of CADS will only be discovered as the system is developed and expanded. However, experience to date indicates great promise.

12.2.4. Suitability for the chosen computer system

The structure of CADS was devised with a minicomputer in mind. The features of most minicomputers are similar, so the general question is that of the viability of minicomputer based systems. The software aspects have already been described in Part II of the thesis; here, the other aspects are considered.

The size of the computer is the most important single factor in determining the feasibility of such a design system. During the development of CADS, problems were encountered due to shortage of both memory and disc space. The problems were overcome by using these resources more effectively, but as development of the system continues, problems may recur.

Having established precedents for desirable programme size, it is unlikely that memory requirements will increase significantly unless additional design terminals are added. Even if extra memory is required, there is scope for expanding the computer system to double the present amount of memory, thus this is not a serious problem.

Disc space is more likely to need increasing to accommodate new programmes and further data storage. This expansion may be achieved in one of two ways: either by buying more discs and adopting an approach whereby each computer activity will necessitate having the correct disc loaded, or else by buying more or larger disc drive units to allow more information to be stored on-line. These alternatives will not be discussed further here as it is sufficient that scope for expansion exists.

The calculation speed and the disc access speed of the computer, combined with sensible programming, has resulted in efficient interactive programmes being produced for the company's computer. Very large programmes (greater than 30k) have been accommodated by using various size reduction techniques. Provided that programming standards are maintained there should be no serious programming problems in the future.

Of the design office staff, one engineer has been given specific responsibility for the computer management, but other than this, job descriptions have not been altered.

This summary shows that the concept of a minicomputer-based design system proved quite viable for the sponsoring company and suggests that a similar system should prove satisfactory for other companies.

12.2.5. Other benefits for the company

In addition to those already mentioned, a number of further benefits accrue to the company. The system has effectively increased the company's capacity to handle various design and development tasks. For instance, the capacity to produce tenders for prospective customers has been considerably increased. The system also ensures greater rationalisation of design procedures and ease of maintenance, as all the design software is produced to a common standard. This will become more apparent as further software is added to the system.

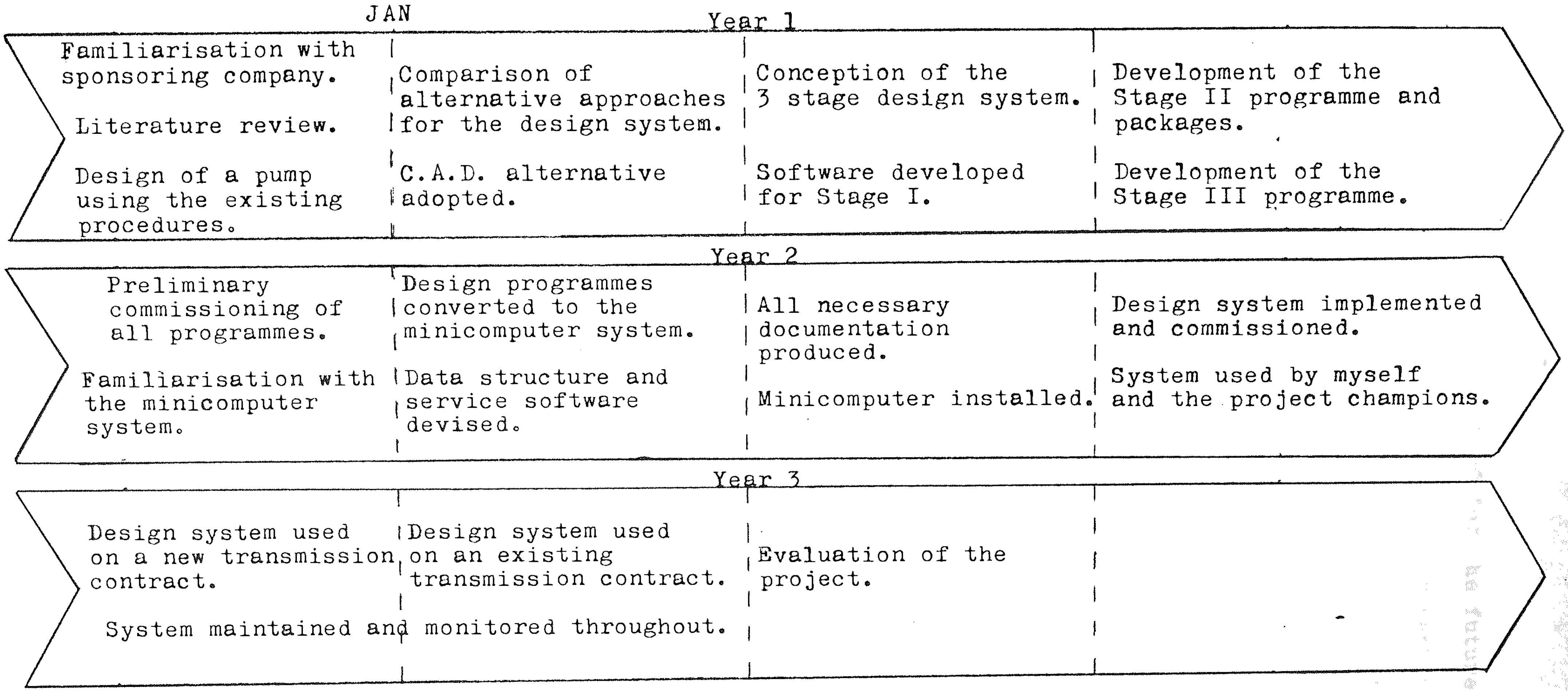
A further benefit to the company ensues through the company being regarded as more modern by its customers, as a result of the use of computer aided design. The prestige attached to C.A.D. will normally enhance the reputation of a company. This may be reflected in terms of orders placed with the company.

Opposing these benefits, there are one or two disadvantages. The design procedures have naturally become very dependent on computer reliability, and it is also necessary that the company employs one or two staff with a substantial knowledge of the computer. Neither of these points pose serious problems provided that they are recognised and suitable insurance is taken out.

Critics might argue that this project constitutes the first step to total automation of the design procedures. As described in chapter 4 of this thesis, this would be both impractical and unacceptable in the field of evolutionary design. However, provided the development of CADS continues according to the precedents set out to date, then the critic's arguments should prove unfounded.

12.3. Discussion

Figure 12.3 is a timetale of the whole project, showing the different phases from the original declaration of the brief, to the evaluation of the released system.



	JAN		
Year 1			
Familiarisation with sponsoring company. Literature review. Design of a pump using the existing procedures.	Comparison of alternative approaches for the design system. C.A.D. alternative adopted.	Conception of the 3 stage design system. Software developed for Stage I.	Development of the Stage II programme and packages. Development of the Stage III programme.
Year 2			
Preliminary commissioning of all programmes. Familiarisation with the minicomputer system.	Design programmes converted to the minicomputer system. Data structure and service software devised.	All necessary documentation produced. Minicomputer installed.	Design system implemented and commissioned. System used by myself and the project champions.
Year 3			
Design system used on a new transmission contract. System maintained and monitored throughout.	Design system used on an existing transmission contract.	Evaluation of the project.	

FIG. 12.3 Progress of the project

Further development of CADS is planned for the future to incorporate the results of further research presently being undertaken by the company. As well as additions to the design software, the information retrieval software will also be expanded to include further design information. The framework which has been developed should be able to cope with considerable expansion as indicated in section 12.2.

Reflecting on the schedule of work, it appears to have progressed smoothly from start to finish. The total period of 2½ years would probably have been reduced to 2 if a suitable minicomputer had been available at the start of the project. However, this would have considerably affected the early stages of the project as there would then have been a much stronger bias towards using a minicomputer as a basis for the system.

Other companies planning a review of their own evolutionary design procedures ought to be able to learn from the experience of the sponsoring company. A few suggestions are listed below.

(i) It is essential to thoroughly investigate existing design procedures before trying to improve or replace them.

(ii) Of the three approaches to design: analysis, synthesis and automation, synthesis is most suitable for a systematic, designer-controlled design method.

(iii) If new or modified design procedures are to be successful it is necessary to consider not only the technical requirements, but also the interface with the prospective users. Furthermore, the design procedures themselves must allow the designer sufficient flexibility to consider the non-technical aspects of the design work'.

(iv) Initial proposals for new design procedures should be kept as flexible as possible, especially if purchase of hardware is to be left until late on. This will also ensure that the final procedures can be easily updated and developed after they are released.

(v) New procedures may be introduced gradually by staging the release. For instance, in this project, periods of limited and full release led up to the official release. Leaving the official release until last minimises the amount of paperwork necessary during the rapid development of the system, and also avoids the possibility of a half-developed system being released to critical staff.

(vi) Once released to the design office, it is important to monitor the use of the new procedures and act swiftly on reasonable criticisms, in order to gain the confidence of the users and maintain the usefulness of the procedures.

It will be noted that there are no specific suggestions on computer-aided design in this list. The arguments leading to adoption of this aid category were expounded in chapter 4, but these arguments will not necessarily apply to other companies. Suggestions for a suitable philosophy for computer-aided design systems were expounded separately in chapter 6.

The maximum benefit of this project was effectively determined by factors beyond the scope of the project. Although considerable improvements have been made in the area of design analysis, as would be expected a new bottle-neck has arisen further along the design process. Design schemes can thus be produced more rapidly than they can be fully developed and evaluated. In this project, the overall result for the company was still a substantial improvement in the capacity to handle design studies. However, other companies should consider carefully where the new bottle-neck will arise before proposing vast improvements in specific areas.

Finally, it is worth reiterating that the improvements achieved did not involve vast sums of money. As suggested in chapter 2, the emphasis must be on compromise between satisfaction of the objectives and expenditure of resources. Careful thought and planning can achieve a great deal, especially if the problem is regarded from the user's viewpoint.

12.4. Recapitulation

This thesis has provided arguments and examples concerned with establishing:

(i) The viability of a minicomputer based design system.

(ii) A suitable method for implementing such a design system.

(iii) The nature of effective interaction between the designer and the system.

Two key aspects of the system viability have been discussed: the cost and the capacity. In chapter 4 the cost was shown to compare favourably with the other alternatives considered. The design system devised in this project was evaluated earlier in this chapter. The system results in considerable reduction in the time and cost of design and development (see table 12.1 and fig 12.2). The capacity of the minicomputer has proved quite adequate; sophisticated programmes, some originally greater than 30K in size, have been accommodated comfortably.

Two novel methods were used to facilitate implementation of the design system. These were the use of project champions, to promote the use of the system,and the idea of releasing the system in stages (chapter 9). These methods complemented each other and resulted in the smooth implementation desired.

The whole of chapter 6 was devoted to the style of interaction adopted for the system. Two features that contribute greatly to the success of the system are:

(i) The concept of the feasible design chart which clearly shows the designer the constraints on the design and also allows him to manipulate these during programme execution.

(ii) The option of typing HELP in reply to yes/no questions, which provides a simple but effective means of ensuring that the designer retains ultimate control of the design procedures.

The overall result of the project has been the successful implementation of improved design procedures in the sponsoring company.

APPENDICES

A. AIDS TO DESIGN

- A.1. Introduction.
- A.2. Mental aids.
- A.3. Charts, tables and diagrams.
- A.4. Models.
- A.5. Experiment.
- A.6. Analytical tools.

B. SUGGESTED DESIGN MANUAL ENTRIES

- B.1. Possible extracts from an improved design manual.
- B.2. Use of design charts.

C. LISTINGS OF C.A.D.S. DESIGN RUNS

D. EXAMPLE OF THE C.A.D.S. USER DOCUMENTATION

APPENDIX A

AIDS TO DESIGN

This appendix is the result of a review of design aids undertaken by the author early in the project. It is intended to reinforce the arguments of sections 2.2, 4.1 and 4.2.

AIDS TO DESIGN

A.1. Introduction..

As time goes on, the number of design aids and techniques available to the designer increases. Some of the fields of knowledge, such as computer technology, are expanding very rapidly and revolutionising design procedures in some areas. On the psychological side too, much work is being done to assimulate and classify the numerous mental aids that might be used. Not so long ago many designs were based primarily on experience, the current doctrine being laid down in a design manual of some sort. The calculations were then often carried out with just a slide rule. Now the slide rule is virtually obsolete and where manuals are used they are not the thick texts they used to be, nor do the codes set out in them have the same permanance.

In this appendix then, we will review some of the aids which the designer might use. Such a review is essential to the project undertaken for the company.

The next section deals briefly with purely mental aids to guide or stimulate the mind of the designer. The remaining sections are concerned with physical aids to design and analysis and the tools or methods relevant to their use.

A.2. Mental Aids.

A.2.1. Aids to creativity.

Probably the two most common mental aids are the methods of brainstorming and synectics. These are mainly concerned with stimulating creativity or inventiveness by encouraging the designer to look at the problem in a new light. Many problems have been solved by these methods, although often the designer is unaware that he has used the aid as such.

Brainstorming involves a number of people, (usually of different disciplines, who might contribute to the problem solution), gathering together to generate ideas. The ideas are noted and discussed at the session, but are usually not evaluated or rejected until after the session. In this way the contributers feel less inhibited and more ideas are generated. All too often a designer may be reluctant to make a suggestion to a production manager (or vice versa) for fear of ridicule. Brainstorming sessions should prevent this.

Synectics is a method of analogies. In addition to direct analogy (such as the popular electrostatic/ electromagnetic and electrodynamic/hydrodynamic analogies), personal analogies may also be used. A person in the group might throw light onto a bearing failure by imagining himself to be the bearing, that is considering the environment, the forces, and transient effects which he would experience. This method too is usually carried out in teams.

The two methods discussed here are treated more fully by Alger & Hayes[27].

A.2.2. Aids to evaluation

Now we consider the mental aids to evaluation. Check lists and matrix analysis fall into this category. The use of check lists is self explanatory, the aim is to focus the designer's attention on each issue in turn. The kind of classification used in such lists will depend on the problem. Sometimes it might be beneficial to consider the subjects or components: for a pump we might have pistons, shaft, bearings etc. Other times, the performance characteristics might be considered: power, efficiency, reliability.

This method is often extended to include direct comparison of alternatives by weighting the criteria, (P.C. Gasson [28]). For instance, we might carry out an evaluation of four pumps using the criteria shown below.

	Maximum Mark	A	B	C	D
Efficiency	3	3	1	2	2
Reliability	4	2	3	1	3
Weight	5	3	3	5	3
Volume	4	2	3	4	2
	16	10	10	12	10

TABLE A.1 Check list for comparison of alternatives

However, unless care is taken with this method, anomalous results can be obtained through choosing designs which excel in only one respect. Notice that the best choice above has the lowest reliability. Thus, it may be necessary to put a lower limit on the permissible score for each criterion.

The matrix method of evaluation (Beakley & Chilton) [29] is usually used in creative design, although in principle there is no reason why evolutionary design should not benefit too. Normally two or three dimensional matrices are used to show the relationships between different classes of design parameters.

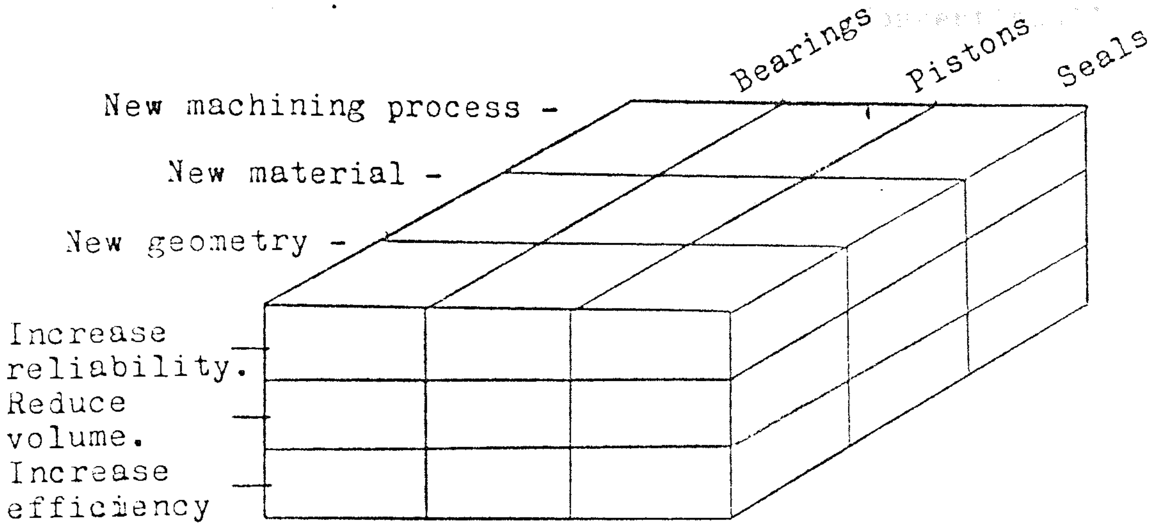


FIG. A.1 The Matrix Method of evaluation applied to the design of pumps

The above sketch shows one way in which a three dimensional matrix might be used to investigate ways of improving the performance of a pump. However, it is usually difficult to represent and to digest three dimensional information (especially since this is normally only presented in two dimensions). Therefore, it is advisable to use two dimensions only, whenever possible. This will usually involve tabulating the alternatives against the likely consequences in some way.

These then are probably the most common mental aids. There are many more: morphological charts, boundary searching, black box design, too numerous to mention, but worthy of consideration in the context of the specific problem. J.C. Jones [30] lists a large number of these mental aids and the corresponding stage of problem solution that might benefit from their application.

A.3. Charts, Tables and Diagrams.

A.3.1. Simple charts and tables.

We now consider the more practical aids. Conventionally charts, tables and diagrams are presented on paper in two dimensions. They may represent well established theoretical or empirical data; for instance steam tables, gas flow tables and charts, material properties, or they may be used to represent or store information peculiar to a particular company or product; past product information or standard sizes. Design tables and simple charts often compete for the same kind of information. For instance steam tables and Mollier charts show essentially the same thing. The benefit of charts is their ease of use, but tables generally allow greater accuracy, by interpolation if necessary. However, in spite of this, design charts, especially some of the more elaborate ones, can be very flexible and useful indeed.

Simple performance charts can show simultaneously the variation of many parameters as some controlled variable is altered. For instance, volumetric, mechanical and overall efficiences or, torque and power may be plotted against speed, or pressure, or machine attitude. This kind of chart may be plotted from empirical or theoretical data.

A.3.2. The nomogram

The nomogram is fundamentally different. It usually represents design equations and so not only indicates the characteristics of the system concerned, but also allows direct evaluation of certain parameters without calculation. The basic linear nomogram consists of a number of parallel straight lines representing the various variables. By laying a ruler across successive triplets of lines such that two lines are intersected at known values, it is possible to determine the value of the unknown variable. This in itself is a valuable and flexible tool since it can deal with a large number of functional relationships, but still more covenient to use are the non-linear nomograms which later developed. These can be derived to suit a large number of different problems, for instance to calculate the H.P. of a petrol engine given the bore, stroke and speed. (This example and many others are given by Hewes & Seward [31].) A further advantage of these nomograms is that they can be used in reverse to calculate (say) the speed at which a given H.P. is attained. Allcock [32] gives a detailed description of the theory and derivation of various classes of nomogram. However, it would seem that the value of nomograms in engineering design was never fully exploited and nowadays the technique seems to have been superseded, in the texts at least, by interest in computer techniques. Perhaps before long we will be using computer produced nomograms!

In 1974 Martin [33] revived some of the interest in design charts by describing two methods closely related to nomograms. These are the sloping grid technique, and slide charts. An example of a simple slide chart used in journal bearing design is given by Martin [34].

But Cuthbertson [35] suggests probably the most serious shortcoming of all such design charts when he says "Few of them are accurate or detailed enough to yield a complete design, because of the limit to the number of variables which can be handled on two-dimensional graph paper." Nevertheless the clarity of many design charts, and their ease of use is a tribute to their designers who must have made every effort to decide what the user wanted to know, and what he was likely to know already. This kind of designer orientated approach should be considered for all design aids.

A.3.3. Performance charts, feasibility charts and linear programming

Moving on to different kinds of charts, performance charts are widely used. As described earlier, generally speaking the main performance criteria are plotted against a controlled variable. (e.g. torque and power against speed for an engine). This will often allow optimisation with respect to certain parameters to give a best overall performance, or it may indicate ways in which the design might be, or might need to be improved.

Feasibility charts are also very useful when it comes to optimisation, or even just satisfaction. The aim is to represent the range of feasible designs allowable to the designer. An example of this technique in the design of electrical machinery is given by Godwin [36] (fig A.2). In addition to enabling a feasible design to be chosen, the chart also shows the designer which constraint is limiting his design choice and allows him to examine this constraint to see whether re-design or new technology can shift it back, so producing a larger feasible design area. Often to optimise the design for one criteria, it is desirable to design close to a particular boundary or at a corner of the feasible area. In this case only these restricting boundaries need be examined.

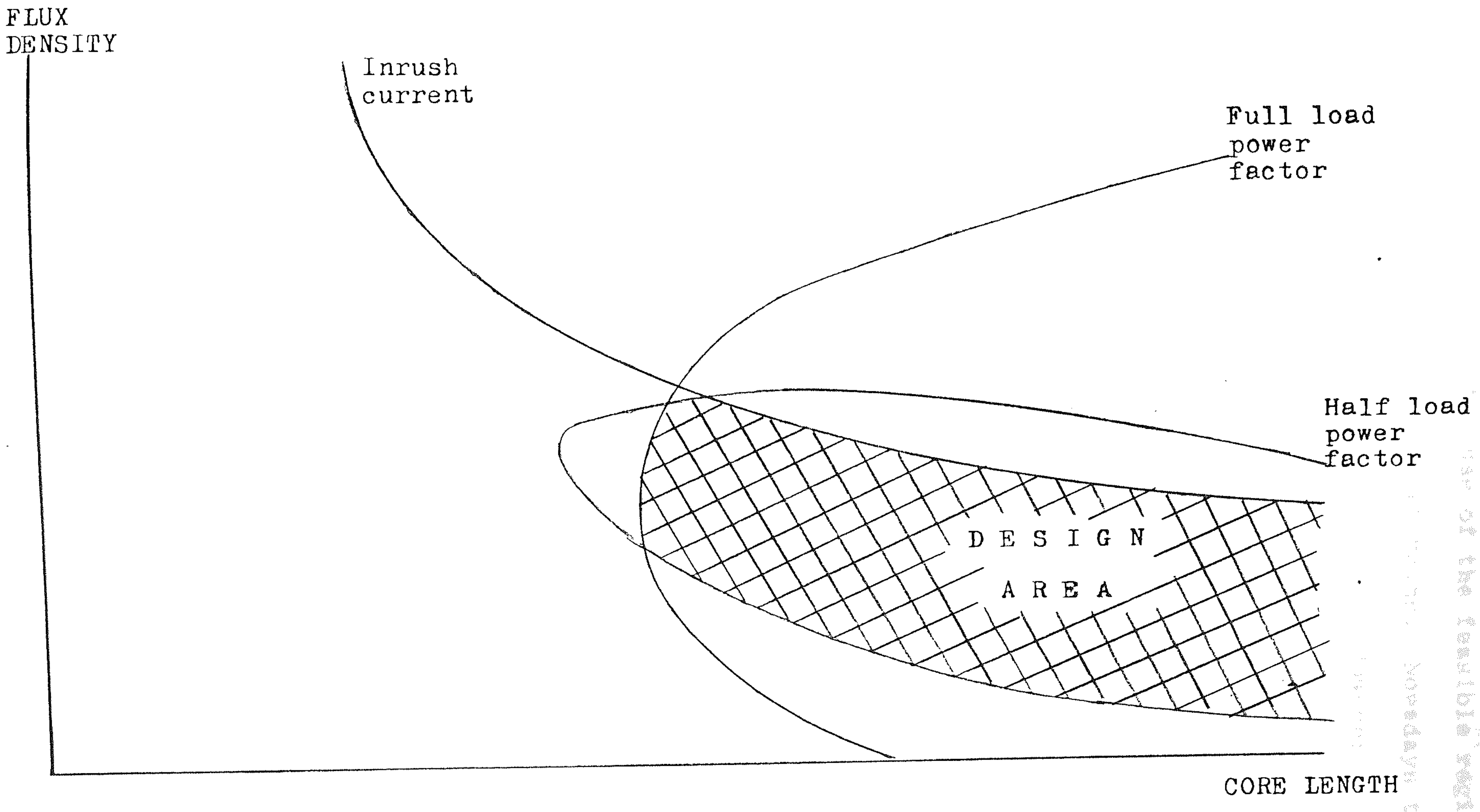


FIG. A.2 Godwin's performance chart for electrical machine design

One technique in which the use of the feasible region technique is inherent is linear programming. Nowadays this method is usually undertaken by computer. However, D.J. Leech [37] gives a good description of the basic principles, taking the example of real two parameter optimisation problems subject to constraints and a criterion function to be optimised. This acts as a very good introduction to the subject, and also explains more clearly some of the ideas behind the feasible region technique. In its own right, the two parameter case has many uses in real design problems. The application of computer techniques can allow more general optimisations in "n-dimensional" space.

So we have discussed some of the design charts that may be used. Other such aids; space diagrams, circuit diagrams, flow charts, are also very useful in planning, preparation or analysis. Probably these fall into a category somewhere between mental and physical aids, and are generally aids to conception. The possible uses of these are naturally very diverse and depend on the nature of the problem. Once the problem has been stated, many situations in which these charts would be beneficial will arise.

In this section then, we have essentially discussed paper models of one sort or another. In the next section we go on to discuss other kinds of models which might be used.

A.4. Models.

In design work it is invariably possible to obtain more information relevant to a particular problem provided one is willing and able to expend the necessary resources: time, manpower, and money. The use of models is one way in which this information can be obtained, but it requires a great deal of skill to decide on the necessary complexity for the proposed model. Finding the right balance between resource expenditure and quality of results can be a difficult business.

"The art of model making", say Beakley and Chilton [38] "consists in selecting the most appropriate degree of simplification and in assessing the importance of the effects that have been neglected in making the assumption.

The subject of modelling is very diverse. At one extreme we have physical models often preferred by the practical designer. At the other extreme are the purely mathematical models. Here we shall distinguish between three basic types; these are mathematical, analogue, and physical. All three types have a wide range of application throughout the design process, and it is essential that all three approaches are considered if the best use is to be made of the available resources.

To give a clear comparison of these three types of model, we will now discuss each in detail.

A.4.1. Physical models

The physical model may be scaled up or down from the real product, it may be made of a different material; often both of these are true. Visually, however, it will be geometrically similar to the full size product.

Scaled up models can be used to magnify effects so that they may be seen more clearly. Scaled down models can often reduce costs and make experiment more practical. Wind tunnel models and ship models fall into the latter category.

It is often desirable to use different materials with specific properties. The most common example of this is perspex which is often used to model steel or other metals because of its photoelastic properties.

The main difficulty in producing physical models is in making sure that the relevant effects are scaled correctly. Here the method of dimensional analysis is useful as it allows the relevant parameters to be grouped for scaling. Thus, in the field of fluid mechanics; if viscous effects cannot be neglected, we have to ensure that the Reynolds number is the same for the model and prototype; if surface effects are important we have to consider the Froude number, and so on.

A problem arises when we need to model several effects simultaneously, and then we often find that even with a change of material, it is impossible to obtain the necessary correspondence between the model and prototype.

Despite these restrictions, the use of physical models can be very rewarding, especially when the behaviour of the design is known to be dominated by one or two effects.

A.4.2. Analogue models

Analogue modelling depends on the similarities of different natural phenomena. For instance, the similarity of the equations governing magnetism, electric field theory, and fluid mechanics. Indeed, without too much difficulty it is possible to see analogies between all fields of physics and engineering, and it often happens that the designer has been thinking analogously about a problem before the formal model is devised.

Most of us have a preference for certain disciplines in engineering, and so analogue models can, for example, help the electrical engineer to picture streamlines and pressure potentials. Additionally the conversion process associated with this analogous thinking may stimulate new approaches to the problem so that mathematical and physical models pertinent to one dicipline might be used to solve problems in others.

Probably the most popular use of analogue modelling is made possible by the analogue computer. Here the electric potentials (at various points in a circuit of operational amplifiers, capacitors, and resistances) represent the variables in differential equations. Since most physical laws can be stated in the form of differential equations, analogue computing provides a quick and efficient way of representing the behaviour of systems subject to these physical laws. This method also has the advantage that parameters (such as stiffnesses, natural frequencies and time constants in a mechanical system) can be altered rapidly, and so the behaviour of the system can be investigated under different conditions.

Analogue computing is generally used to model dynamic or transient effects. However, with a little forethought the methods can be applied more diversely.

A.4.3. Mathematical models.

Mathematical models are those in which the product to be simulated is represented by a set of equations which purport to predict the behaviour of that product. Usually the equations used are based on the laws of physics and it may often be necessary to satisfy a number of equations in order to obtain a solution to the problem. Naturally, it is desirable that the equations are of a simple form so that by substituting values for the known variables, the unknown variables might be calculated directly. Unfortunately such is the complexity of most problems that this cannot be achieved. To obtain the required information it may be necessary to solve several equations simultaneously. In some cases the form of an equation may be such that it cannot be solved directly and a trial and error method will be necessary.

It is in these circumstances that the value of a digital computer becomes apparent. Since these allow arithmetic to be performed very rapidly, the iteration necessary to solve the mathematical equations will take very little time. The designer can then treat the mathematical, or computer model (as it should now be called) as a black box which accepts the conditions imposed by the designer and calculates the consequences. In this respect the computer is in fact behaving like a physical model.

Let us consider a mathematical model for a journal bearing.

Equations representing the load carrying capacity, the heat generation rate, and the fluid flow rate will have to be solved. These will be coupled by virtue of their effects and dependence on bearing attitude and fluid viscosities. Hence an iterative approach will be necessary. However, it will be possible to arrange the computer model so that it accepts the bearing load, speed and unit properties and predicts the eccetricity, clearance, and running temperature i.e. to perform any iteration necessary to the desired solution form internally.

An extra advantage of the mathematical model is that it allows us to discover the values of parameters which would be very difficult to measure on a physical model, for example, internal clearances on a machine.

As with the other classes of model, mathematical models are only as good as the assumptions behind them. If inadequate equations are used, then the results too must be inadequate.

Here then we have discussed the ways in which models might be used in the design process. For a further comparison of the different types, the reader is referred to Gregory [39].

A.5. Experiment.

Having just discussed various models, it is probably the right time to mention experimentation, (which usually concerns, if you like, full size physical models). Firth [40] feels that there is a tendency to overplay mathematical theory and disregard data giving situations. One reason for this situation may be the assumption that, once a full size prototype has been manufactured and is ready for testing, then the design phase is complete. In the narrowest sense of design, this is true, but the following three points should be remembered:-

(i) It is often possible, and advantageous, to test components of the proposed final product, in isolation. This will not only give extra information about the component, but might also have implications for the product as a whole. It might, thus, be possible to make design modifications before the complete prototype is built.

(ii) Tests on existing machines in the same, or related, design families, will often yield valuable information for new designs. For instance, it might be desirable to drive "last year's model" until it fails in order to decide what changes should be made to this years model. Alternatively last year's model might be modified to simulate the proposed new design in some but not all respects.

(iii) If the new product is to be produced in large numbers, it will be necessary to carry out extensive tests not only on the prototype, but also on samples of each batch. If as a result of this test experience possible improvements are uncovered, then this extra information may benefit later batches. Anyone who has bought a brand new model of a motor car, will appreciate that much is learnt during the early life of a product.

It is always important to record all experimental results, even those that seem anomalous at the time, for these might add the missing piece to a jigsaw at some later date.

So far we have considered tests on the components and on the whole product, but material tests too can be very important. Naturally, there are tabulated values for yield strength, Young's modulus,hardness, fatigue life etc., but it is often worthwhile to repeat these tests to obtain a realistic idea of the scatter for the particular material batches being used.

Finally, a most useful source of experimental data is the customer. Different customers may be using the same product in different environments, possibly to do different jobs, and for differing lengths of time. Information on the performance of the product under these various conditions may come too late to help that particular product, but it may certainly be fed back into the store of knowledge available for future designs.

A.6. Analytical Tools.

In this section we briefly, and superficially, compare the specific design tools. (A more pertinent comparison for the company is given in Part II of this thesis, as part of the Central Design System development). These tools include design manuals and charts (which have been described earlier), the numerous types of desk top and hand calculators, and the use of computers.

Naturally, the kind of tool required is dependent on the nature of the design problems, that is, their complexity and size, and the degree of inter-dependency of the composite facets. However, here we will attempt to compare, in general terms, the use of the various tools.

In an earlier report by the author [41] each of the tools mentioned above was considered as the basis for a design procedure. It was found that it was invariably necessary to use two or more tool categories in conjunction to obtain a satisfactory solution. For instance, if the design procedures were represented by a series of charts, often arithmetic manipulation would be necessary, between the charts, or to obtain more accurate results once a speculative solution had been found.

Usually the manual - chart - calculator combination constitutes an analysis approach to design. The addition of a programmable calculator is certainly beneficial when the analysis involves long, repetitive calculations, but nonetheless,with this kind of an approach, the structuring, planning and ordering of the design procedures is usually left to the designer.

On the other hand, the use of advanced programmable calculators and computers is often indicative of a "design by synthesis" approach. In this situation, not only the analysis, but also some degree of the procedural planning is performed by the machine. At the simplest level this might involve the machine systematically pursuing an iterative procedure until an equation is solved. This class of tool is characterised by the capacity to cope with logical, and calculation control functions, normally by means of "IF", "DO", and "GO TO" statements.

If the synthesis approach to design is favoured, it is necessary to decide between the alternatives of desk top calculator and computer. Mandeno [42] compares the respective benefits of these alternatives and comments that the choice will depend on the size of the design office. It is also worth considering the extra effort involved in installing, programming, and operating a small computer. For any particular company, the pro's and con's have to be carefully investigated before a decision can be made. For instance, in some cases it may be possible to use a small computer for two or more separate tasks, (perhaps design work, data logging, simulation etc.) and obviously this will present an economic advantage in favour of the computer.

In the general category of computers, we should also consider the possibility of remote access bureau services such as the C.A.D.C. Cambridge. This takes us into the vast field of computer aided design,[43] and is beyond the scope of this appendix.

However, it is important to keep an open mind on the use of the different tools discussed. The most effective C.A.D. system might well involve additional side calculations to be performed by the designer, and it might well simply produce design charts. It is worthwhile remembering this before trying to design a C.A.D. system that does everything.

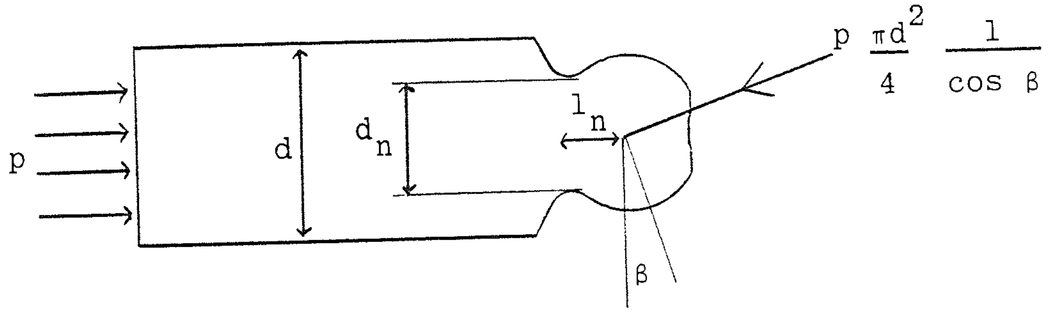
APPENDIX B

SUGGESTED DESIGN MANUAL ENTRIES
(style proposed for a new design manual)

B.1. Possible extracts from an improved design manual

Example 1:

Piston neck design



β = swash angle

p = operating pressure

Strength criterion: The maximum stress in the neck is limited to a fraction $\frac{1}{n}$ of the fatigue limit, (σ_f).

n = load factor

Max. and min. stresses in neck are – $\underbrace{\frac{d^2 p}{d_n^{\,2}}}_{\text{Direct stress}} \pm \underbrace{\frac{8d^2 p l_n \operatorname{Tan}\beta}{d_n^{\,3}}}_{\text{Bending stress}}$

$$\therefore \left(\frac{d}{d_n}\right)^2 \left[1 + 8\,\frac{l_n}{d_n}\,\operatorname{Tan}\beta\right] \leqslant \frac{1}{n}\cdot\frac{\sigma f}{p} \qquad \text{(B.1)}$$

is the strength criteria governing the neck diameter.

(Note: For any particular pump the R.H.S. of the equation is immediately known).

(For the case of $\sigma_f = 45{,}000$ p.s.i., $p = 5{,}000$ p.s.i.

$$\beta = 15^\circ \qquad \frac{l_n}{d_n} = \frac{5}{8} \qquad n = 1$$

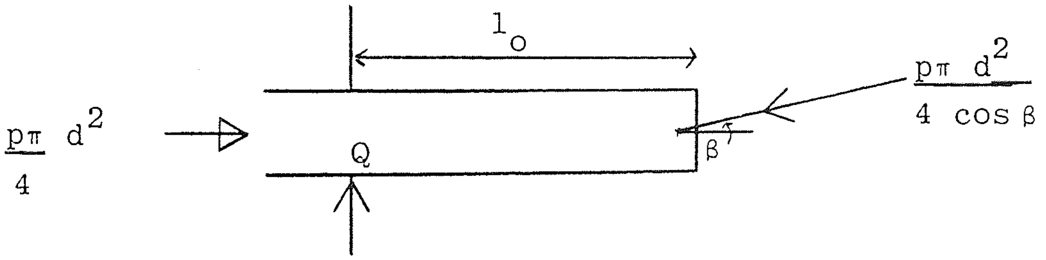
this equation reduces to the form: $(d_n/d)^2 \geqslant .26$

However, the equation is very sensitive to changes in β and l_n/d_n and you are therefore recommended to leave the equation in its general form).

Geometric criterion: [There would then be another equation setting out the geometric limitations on the neck design.]

Example 2:

Piston overhang



d_i = Internal diameter of piston

Strength criterion: The maximum longitudinal stress in the piston (which occurs at point Q) is limited to a fraction $\frac{1}{n}$ of the fatigue limit (σ_f).

$$\text{Max. and min. stresses at } Q = \underbrace{p}_{\text{direct}} \pm \underbrace{\frac{8\, p\, l_o\, d^3 \operatorname{Tan}\beta}{(d^4 - d_i^{\,4})}}_{\text{bending}}$$

(It is worth remembering that an analysis of the hoop, radial, and longitudinal stresses will already have given you a value of d_i/d which satisfies a strength criterion and also possibly a weight criterion i.e. weight as low as possible).

$$\therefore \frac{\sigma_f}{np} \geqslant \frac{1 \pm 8 \operatorname{Tan} \beta \,(lo/d)}{1 + \frac{(d_i)^4}{d^4}} \qquad (B.2)$$

is the strength criterion governing the piston overhang (i.e. a relationship between β and $\frac{lo}{d}$).

Geometric criterion: [Again there will be at least one other limitation relating lo/d geometrically to (say) $\frac{D}{d}$, β, and slipper dimensions.]

B.2. Use of design charts

B.2.1. Nomograms

Example 1: Piston neck design

In section B.1 the strength criterion affecting the piston neck design was presented.

$$\frac{(d)^2}{(d_n)^2}\left[1 + 8\frac{l_n}{d_n} \operatorname{Tan} \beta\right] \leqslant \frac{\sigma_f}{p}$$

This equation is represented by fig B.1 as a collinear nomogram. The values of the five variables are set out on collinear axes. For any given value of four of them, the corresponding value of the fifth can be found by constructing a series of straight lines between the known values.

Thus if β, $\frac{l_n}{d_n}$, p and σ_f were specified as 15°, .28

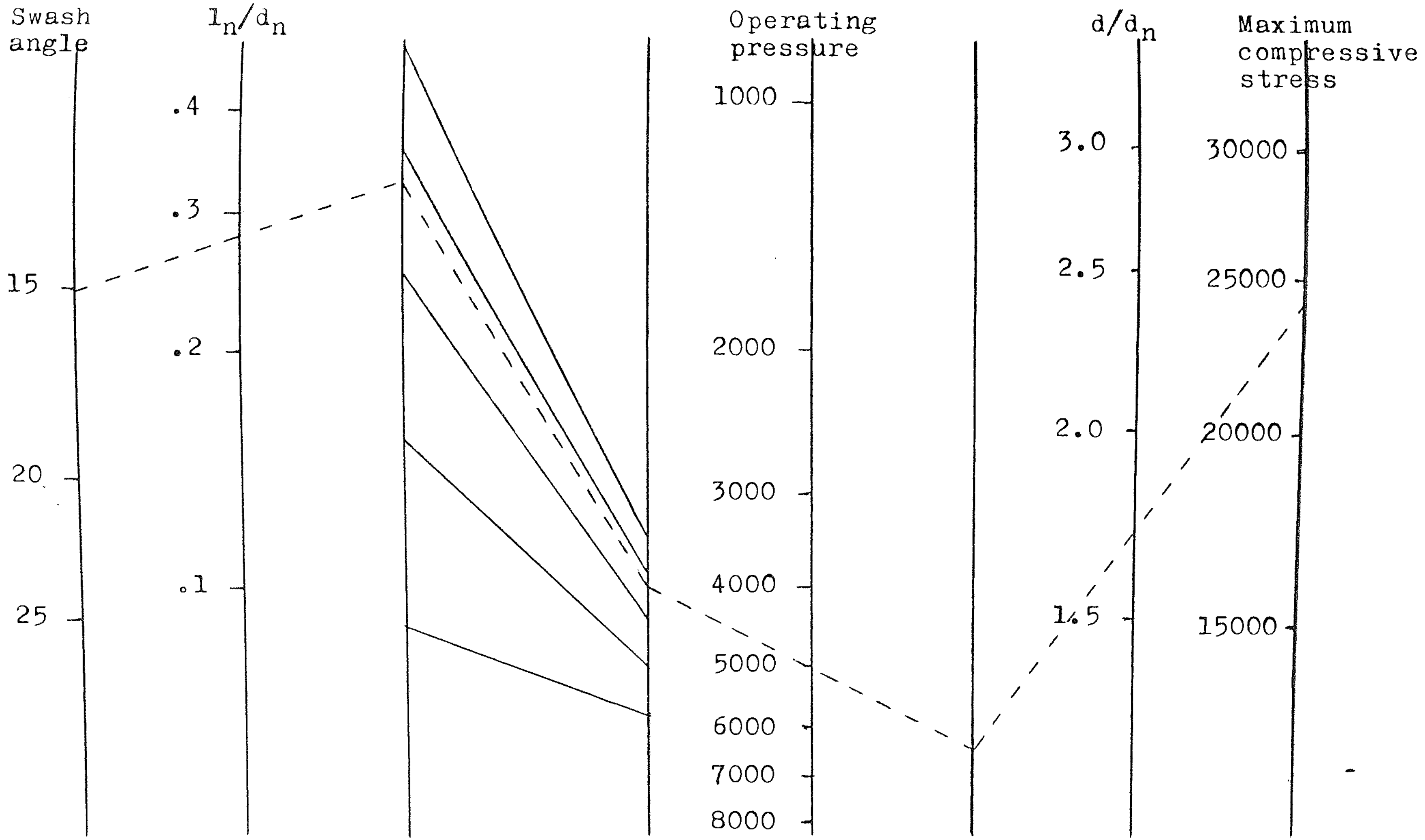


FIG. B.1 Collinear nomogram for piston neck design

5000 p.s.i., 24,000 p.s.i., the maximum permissable value of $\frac{d}{d_n}$ would be 1.7.

Alternatively the equation above can be re-written:

$$\frac{(d_n)^3}{(d)^3} - \frac{(p)}{\sigma_f} \cdot \frac{d_n}{d} - 8\,\frac{(l_n)}{d}\,(\text{Tan}\ \beta)\,\frac{p}{\sigma_f} = 0$$

in which case the equation can be solved for $\left(\frac{d_n}{d}\right)$, given the other variable values, using the cubic nomogram fig B.2. This form of solution has the advantage that d_n only appears in one function (not in two dependent function $\frac{d_n}{d}$, $\frac{l_n}{d_n}$ as in the first case).

(To use the cubic nomogram to solve for $\frac{d_n}{d}$ construct a straight line between the points $\frac{(p)}{(\sigma_f)}$ on the p scale and $8\,\frac{(p)}{\sigma_f}\,\frac{(l_n)}{d}\ \text{Tan}\ \beta$ on the q scale. The value of $\frac{d_n}{d}$ can then be read off the z scale.

Notice that the two nomograms drawn are completely general in that they do not refer to one single size pump or swash angle, but to any piston geometry having the general layout shown in section B.1.

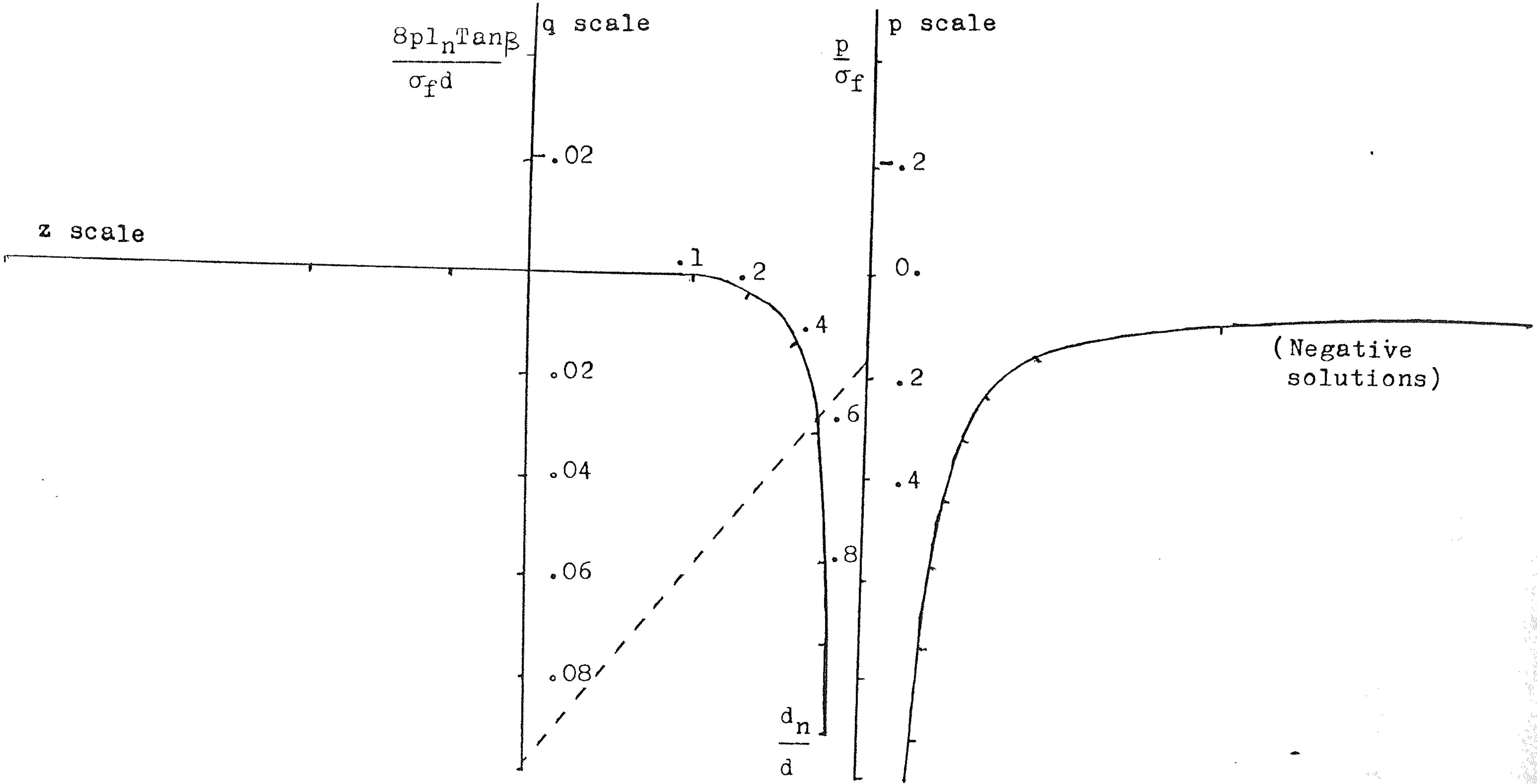


FIG. B.2 Cubic nomogram for piston neck design

Example 2: Flow rate calculation

Figure B.3 is included to give another example of the kind of nomogram that might aid pump design. The equation $Q_{cap} = \frac{\pi d_p^2}{4} D \tan(\beta.) n_p$ can be simply evaluated by arithmetic and it is unlikely the fig B.3 in its present form would be very useful. However, by first juggling with the functions, it is possible that a similar nomogram might be useful in the initial stages of the pump design. (For instance one might simply draw a line on the d - D grid representing the minimum value of D/d allowable, thus limiting the designer's choice).

B.2.2. Design compatibility charts

This is a method of identifying the limiting criterion associated with any design decision. Consider for example the choice of the ratio d/D. We shall consider for the moment only three governing criteria (there are more, but we shall neglect these to simplify the chart).

(i) Slipper spacing. We can write this as:

$$\delta_s = D \sin\left(\frac{360}{2n_p}\right) - kd_p \qquad (B.3)$$

where δ_s is the slipper spacing and kd_p is the slipper base diameter assumed to be proportional to the bore in this example. This criterion is represented by a horizontal line in fig B.4 (which is drawn for k = 1.3, $\delta_s/d_p = .085 \approx 0$.

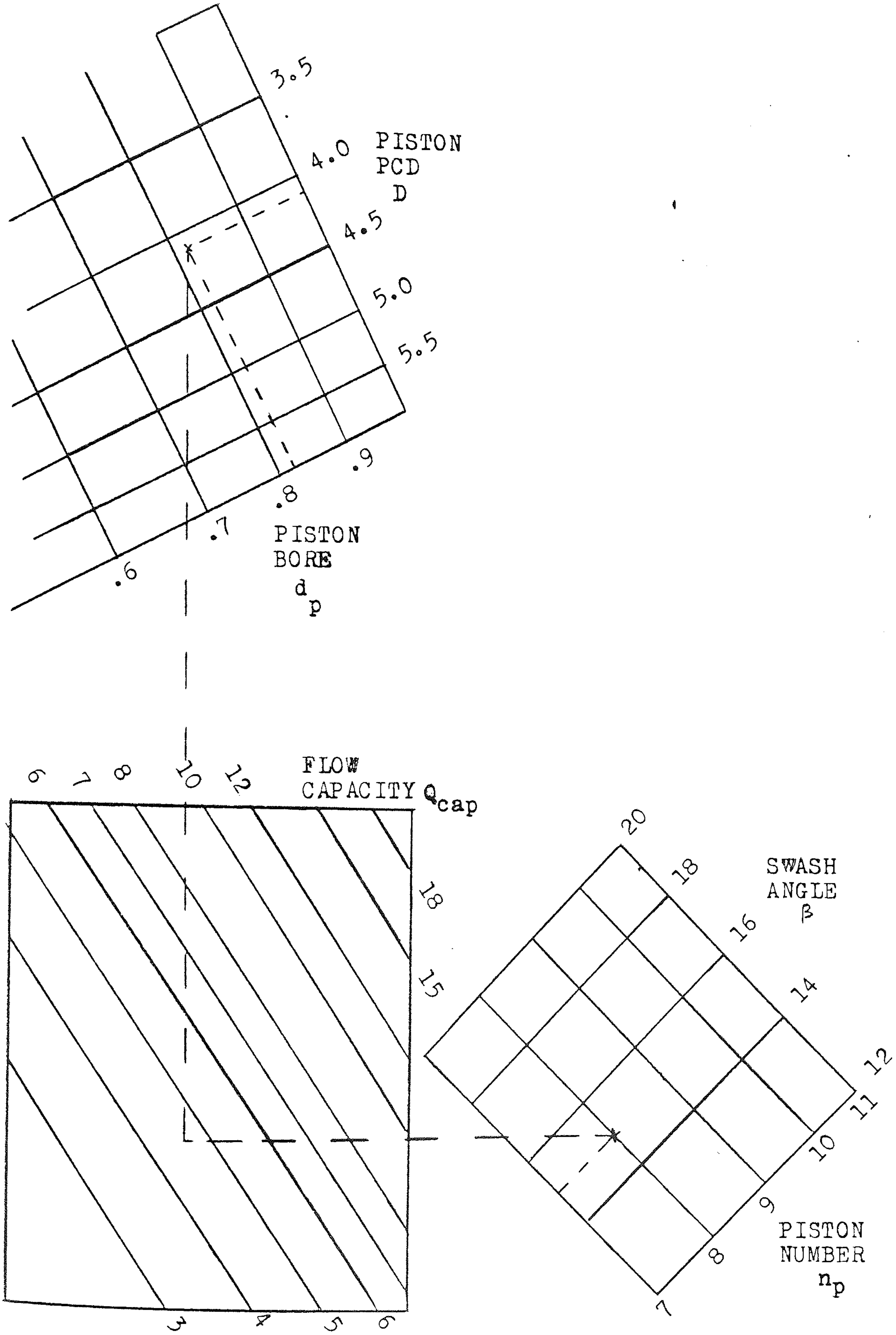


FIG. B.3 Sliding chart nomogram for flow capacity calculation

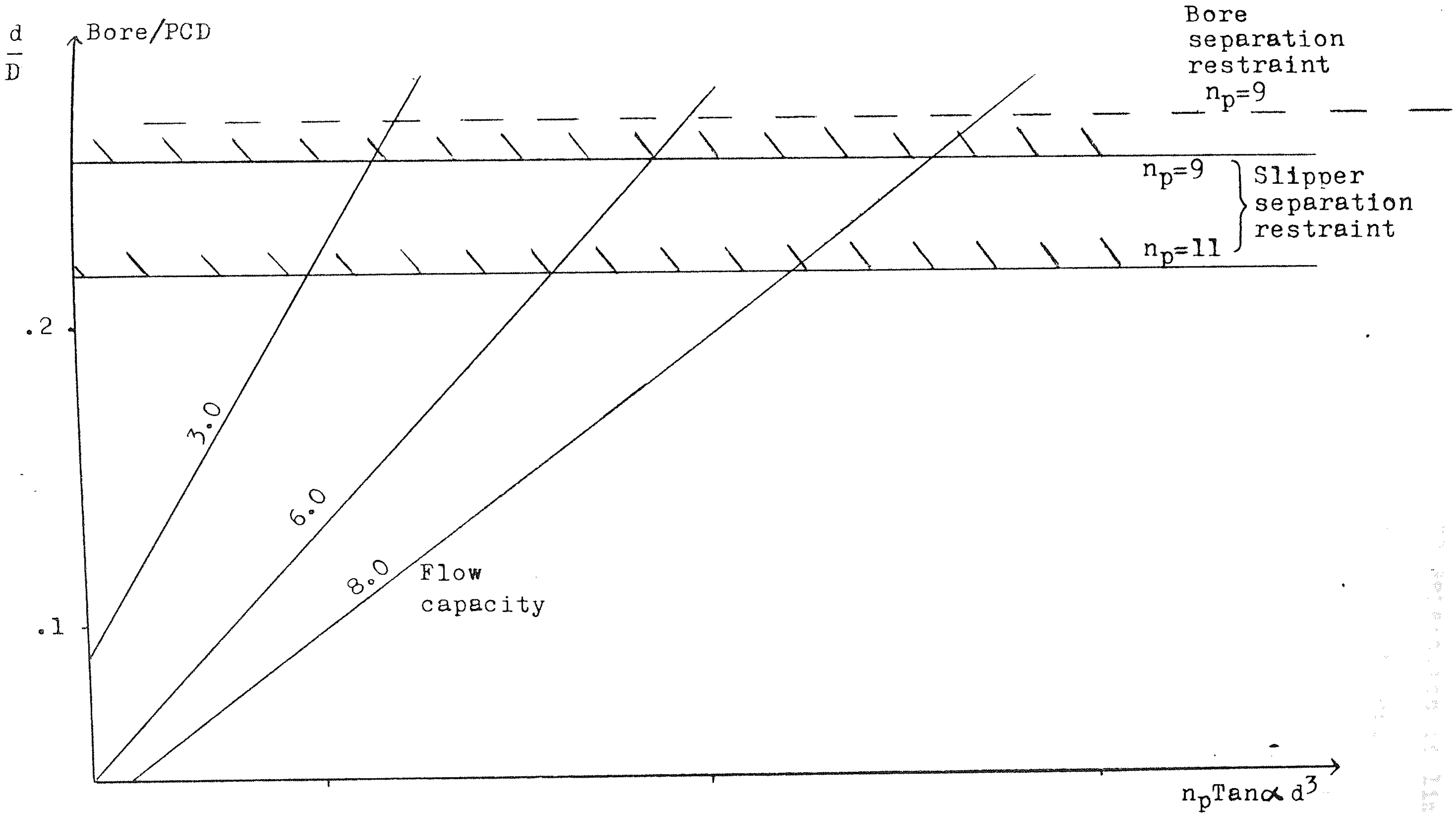


FIG. B.4 Simple design compatibility chart for pump design

(ii) Bore separation. The bore separation is limited by the radial stress between the bores. Applying the thick cylinder approximation to the region around the bores and substituting boundary conditions we have:

$$\sigma_{max} = p \frac{(S^2 + d_p^2)}{(S^2 - d_p^2)}$$ where S is the separation of the bore centres,

p = operating pressure.

The above equation can be re-written

$$\frac{d_p}{D} = \mathrm{Sin}\left(\frac{360}{2n_p}\right)\sqrt{\frac{\left(\frac{\sigma_m}{p} - 1\right)}{\left(\frac{\sigma_m}{p} + 1\right)}}$$

(where σ_m is the maximum allowable value of stress in the material). This is again a horizontal line on the fig B.4 (N.B. The important consideration of centrifugal stresses is omitted in this simple example).

By plotting these lines we immediately see that for the chosen values of σ_m, k etc., slipper spacing is the limiting criterion.

(iii) Flow capacity. On the graph we can now plot equation B.3 for various values of n_p and also represent the limits set by the flow capacity. Having done this a series of "optimum" designs appears at the intersection of the two sets of lines. These optimums can be compared in the light of the respective values they yield for β and d_p. Notice that the final nomogram given in section B.2.1 of this appendix could also be used as a design compatibility chart by constructing a series of lines representing the limiting d:D ratios for particular values of n_p. Using this nomogram , less arithmetic would be needed than with fig B.4.

APPENDIX C

LISTINGS OF C.A.D.S. DESIGN RUNS

Design Feasibility programme	FESPRO
Basic Design programme	DESPRO
Journal Bearing Design package	BEARIN
Cylinder Block Flexibility package	FLEXIB
Performance programme	PERPRO

(Underlining indicates a response from the designer.)

```
 RUN /FESPRO

AXIAL PISTON PUMP DESIGN PROGRAMME
         STAGE1


WOULD YOU LIKE A DESCRIPTION OF THE PROGRAMME?
                                                                  ##Y




THIS PROGRAMME CALCULATES THE POWER,TORQUE
AND MINIMUM DRIVE SHAFT DIAMETER FOR THE PUMP BEING DESIGNED.
IT ALSO PRESENTS THE RESTRAINTS IMPOSED ON THE DESIGN BY THE
FOLLOWING CRITERIA:-
        SLIPPER SEPARATION
        HEAD LOSS AT THE CYLINDER SLOTS
        STRESSES IN THE PISTON NECK
        SUFFICIENTLY THICK JOURNALS
        SUFFICIENT BORE AND SLOT SEPARATION
        SUFFICIENTLY THICK ROTOR INSIDE WALLS
THESE RESTRAINTS ARE PRESENTED ON A FEASIBLE DESIGN CHART
WHICH IS CONSTRUCTED AT THE START OF THE PROGRAMME
TO DRIVE THIS THE FOLLOWING APPLIES:-
  Y=YES,   N=NO,   H=HELP!

PRESS RETURN AFTER EACH ENTRANT
TO CANCEL A CHARACTER  PRESS  RUBOUT
TO CANCEL A LINE  PRESS LINE FEED

                PRESS  1  TO CONTINUE    1


PLEASE CHOOSE A TITLE FOR THE PUMP FILE?    EXAMPLE

WHAT UNITS DO YOU WISH TO USE?

          O=IMPERIAL
          1=METRIC
                    CHOICE?    0
```

```
PLEASE TYPE THE FOLLOWING

          NUMBER OF PISTONS?          9
          FLOW CAPACITY  CIR?         5.0
          PUMP SPEED  RPM?            2500
          OPERATING PRESSURE  PSI?    5000
          BOOST PRESSURE  PSI?        200


NO. OF PISTONS        =         9.000
FLOW CAPACITY         =         5.000
PUMP SPEED            =      2500.000
OPERATING PRESSURE    =      5000.000
BOOST PRESSURE        =       200.000

                              IS THIS CORRECT?
                                                                  ##Y

PUMP POWER IS          151.515 H.P.
WOULD YOU LIKE TO KNOW THE TORQUE?
                                                                  ##N

IS THERE ANY EXTRA TORQUE?
                                                                  ##N


CALCULATION OF MINIMUM SHAFT DIAMETER *****
  PLEASE ENTER THE FOLLOWING:-

  APPROXIMATE STRESS CONCENTRATION FACTOR? 1.5
                        DESIRED LOAD FACTOR? 2

STRESS CONCENTRATION FACTOR =        1.50000
DESIRED LOAD FACTOR         =        2.00000

                IS THIS CORRECT?
                                                                  ##Y


PLEASE CHOOSE A MATERIAL:
 1= EN8
 2= EN19
 3= EN 24
 4= EN25
 5= EN26
 6= ALUMINIUM
 7= IRON

  CHOICE?      3
```

```
CONDITION:
 1=T
 2=V
 3=X      1

          MINIMUM SHAFT DIAMETER =       0.85301 INS

DO YOU WISH TO CHOOSE A SHAFT?

                                                      ##Y

PLEASE ENTER THE FOLLOWING:-
  CHOSEN SHAFT DIAMETER  INS?          .875
  STRESS CONCN FACTOR FOR THIS SHAFT?1.5

THE LOAD FACTOR FOR THIS SHAFT =       2.15975

ARE YOU HAPPY WITH THIS SHAFT?

                                                      ##Y




DO YOU WISH TO SPECIFY THE GRAPH LIMITS?
                                                      ##Y
PLEASE ENTER THE FOLLOWING VALUES IN INCHES:-

LOWEST VALUE OF PCD   ?   2.0
HIGHEST VALUE OF PCD   ?  8.0
LOWEST VALUE OF BORE   ?  .3
HIGHEST VALUE OF BORE   ? 1.9

     CHOOSE DIVISIONS?
                                                      ##N
```

** Feasible-Design chart displayed **
(See fig. C.1a)

```
WHICH DESIGN RESTRAINT WOULD YOU LIKE TO PLOT?
          1=SLIPPER SEPARATION RESTRAINT
          2=CYLINDER SLOT HEAD LOSS RESTRAINT
          3=NECK STRESS RESTRAINT
          4=JOURNAL GEOMETRY RESTRAINTS
          5=BORE AND SLOT SEPARATION RESTRAINTS
          6=ROTOR INSIDE WALL THICKNESS RESTRAINT
        999=HELP!

               CHOICE?    1
```

** Feasible Design chart displayed **
(See fig. C.1b)

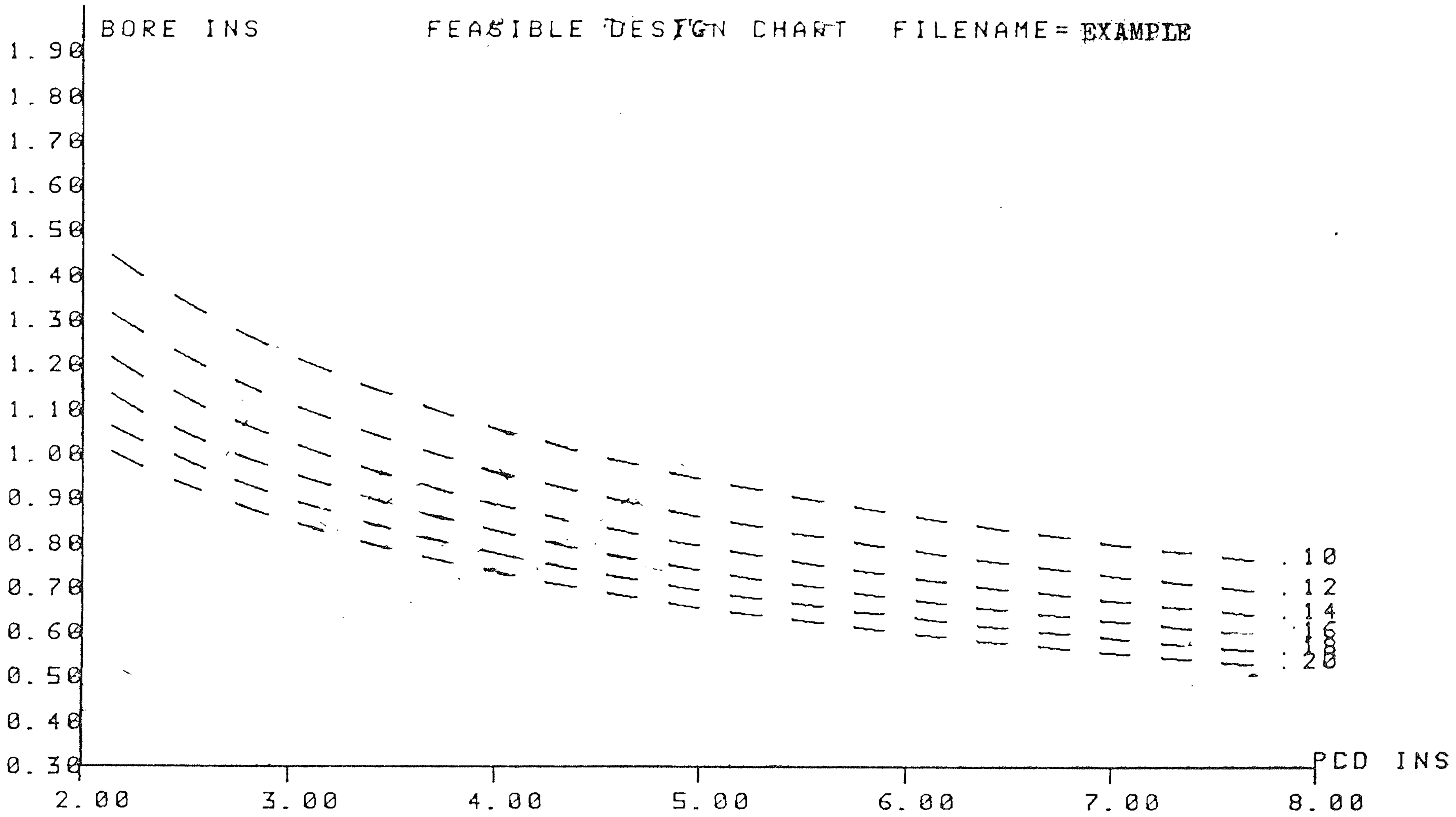


FIG. C.1a Chart produced by the design feasibility programme

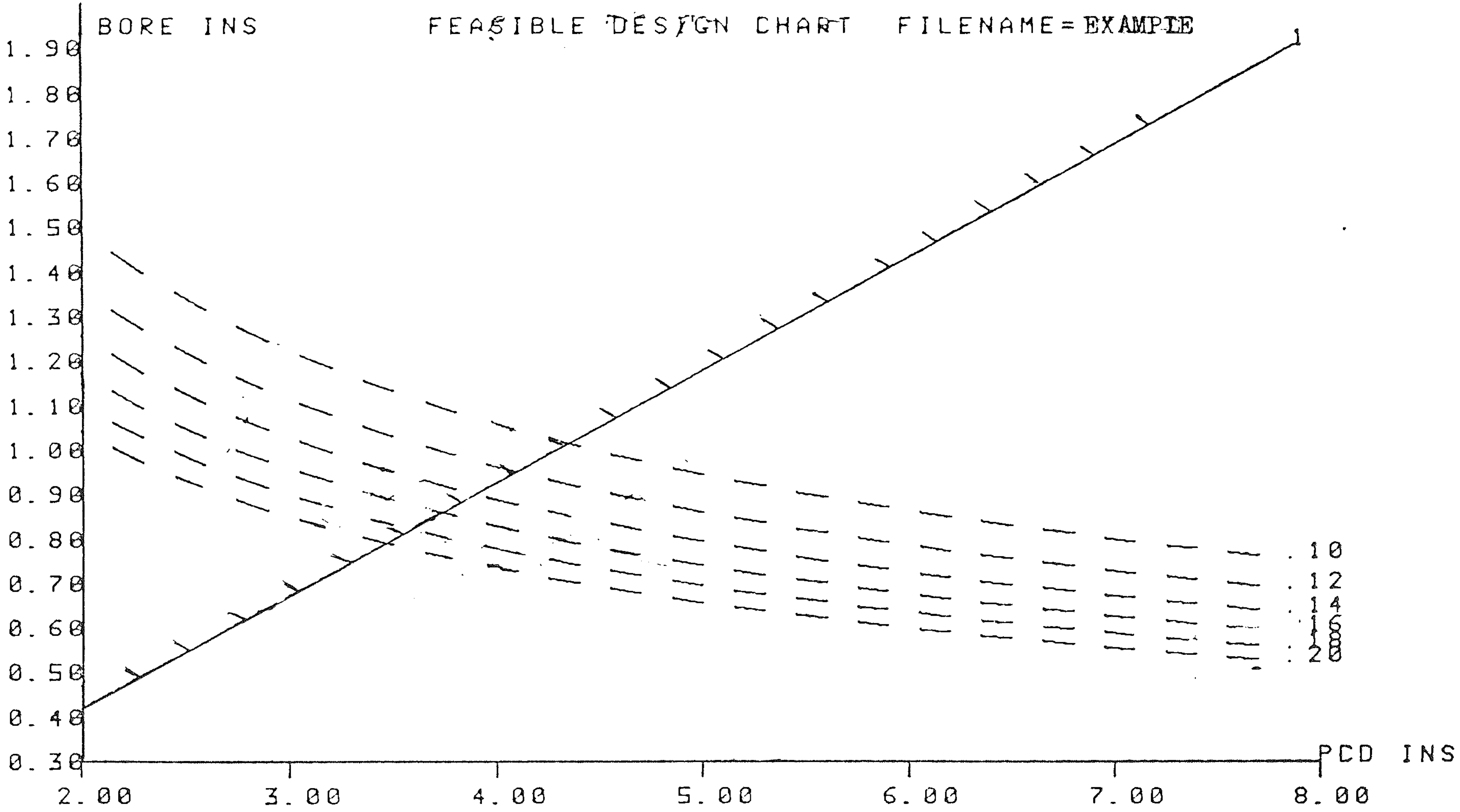


FIG. C.1b Chart produced by the design feasibility programme

```
WHICH DESIGN RESTRAINT WOULD YOU LIKE TO PLOT?
          1=SLIPPER SEPARATION RESTRAINT
          2=CYLINDER SLOT HEAD LOSS RESTRAINT
          3=NECK STRESS RESTRAINT
          4=JOURNAL GEOMETRY RESTRAINTS
          5=BORE AND SLOT SEPARATION RESTRAINTS
          6=ROTOR INSIDE WALL THICKNESS RESTRAINT
        999=HELP!

               CHOICE?     2


CYLINDER SLOT HEAD LOSS RESTRAINT **********
  PLEASE ENTER THE FOLLOWING:-

               CYLINDER SLOT ANGLE? 30

PLEASE CHOOSE A MATERIAL:
 1= EN8
 2= EN19
 3= EN 24
 4= EN25
 5= EN26
 6= ALUMINIUM
 7= IRON

  CHOICE?     1

CONDITION:
 1=N
 2=Q
 3=R      1

COMBINED LAND WIDTH/  WIDTH BETWEEN LANDS  ? 1


[BORE PCD-SLOT PCD]/BORE  =       0.50000

     DO YOU WISH TO ALTER THIS?
                                                                   ##N

WHAT IS THE TOLERABLE HEAD LOSS
       AT INLET  PSI?     15.0
```

```
OIL TO BE USED


PLEASE CHOOSE AN OIL FROM THE FOLLOWING LIST:
               1=TELLUS 15
               2=TELLUS 27
               3=TELLUS 41
               4=TELLUS 72

                    CHOICE NO.?     2
```

** Feasible Design chart displayed **
(See fig. C.1c)

```
WHICH DESIGN RESTRAINT WOULD YOU LIKE TO PLOT?
          1=SLIPPER SEPARATION RESTRAINT
          2=CYLINDER SLOT HEAD LOSS RESTRAINT
          3=NECK STRESS RESTRAINT
          4=JOURNAL GEOMETRY RESTRAINTS
          5=BORE AND SLOT SEPARATION RESTRAINTS
          6=ROTOR INSIDE WALL THICKNESS RESTRAINT
        999=HELP!

               CHOICE?     3


MAXIMUM NECK STRESS RESTRAINT ***********


 PLEASE TYPE THE FOLLOWING:-
SLIPPER ROLLOVER    DEGREES? 13

PLEASE CHOOSE A MATERIAL:
 1= EN8
 2= EN19
 3= EN 24
 4= EN25
 5= EN26
 6= ALUMINIUM
 7= IRON

  CHOICE?     1
```

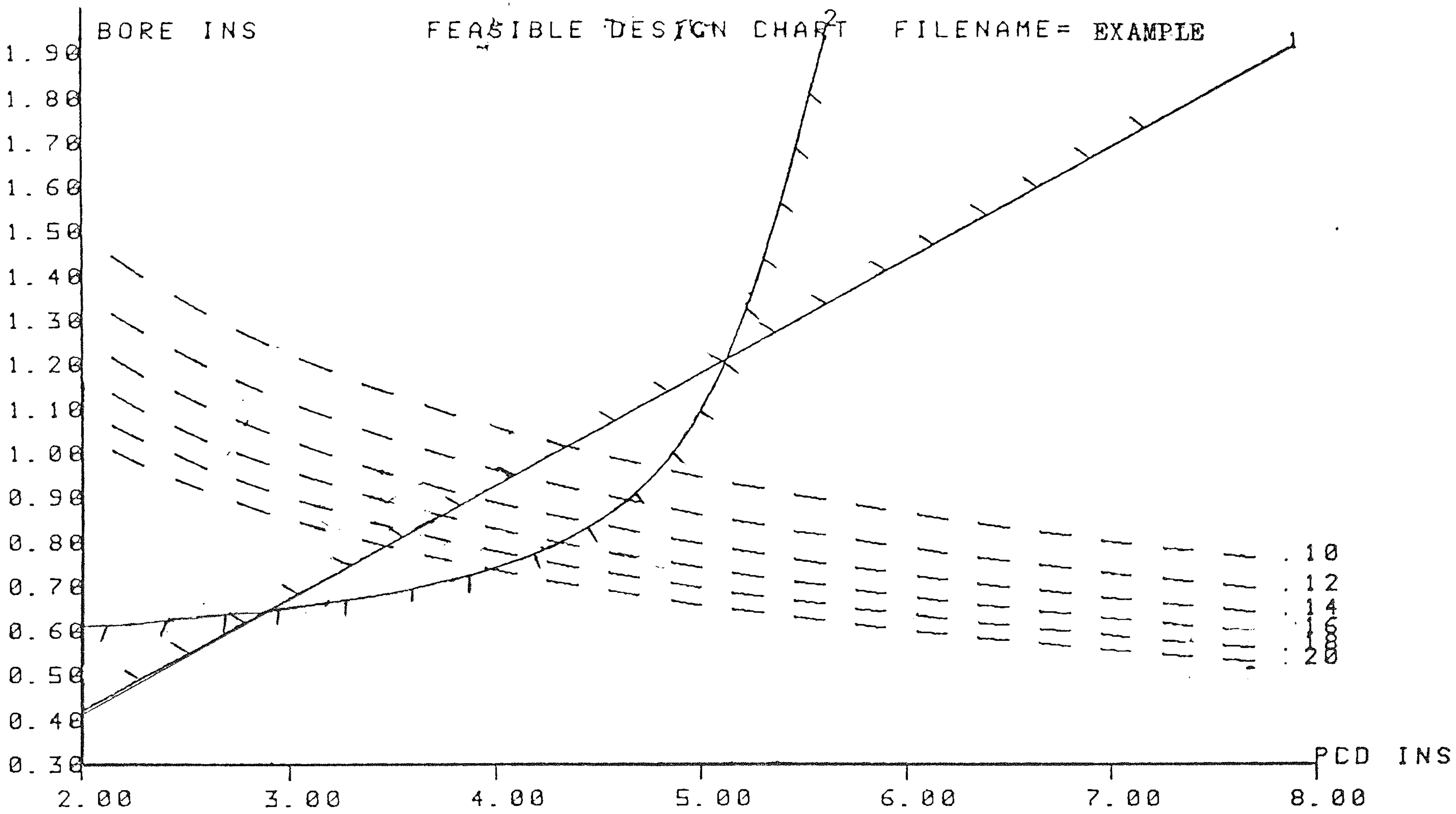


FIG. C.1c Chart produced by the design feasibility programme

```
CONDITION:
 1=N
 2=Q
 3=R      2
```

** Feasible Design chart displayed **
(See fig C.1d)

```
WHICH DESIGN RESTRAINT WOULD YOU LIKE TO PLOT?
          1=SLIPPER SEPARATION RESTRAINT
          2=CYLINDER SLOT HEAD LOSS RESTRAINT
          3=NECK STRESS RESTRAINT
          4=JOURNAL GEOMETRY RESTRAINTS
          5=BORE AND SLOT SEPARATION RESTRAINTS
          6=ROTOR INSIDE WALL THICKNESS RESTRAINT
        999=HELP!

               CHOICE?     4


JOURNAL GEOMETRY RESTRAINTS
     FOR THE ROTOR BLOCK

EARLIER YOU SPECIFIED  COMBINED LAND WIDTH/INTER-LAND WIDTH AS  1.
DO YOU WISH TO ALTER THIS?
                                                                ##N


WHICH JOURNAL WOULD YOU LIKE TO CONSIDER FIRST?
          0=NEITHER RESTRAINT
          1=SWASH END JOURNAL
          2=PORT PLATE END JOURNAL      1


          SWASH END JOURNAL RESTRAINT
     PLEASE CHOOSE SWASH ARRANGEMENT:-
               0=NORMAL SWIVEL MECHANISM
               1=WEDGE TYPE MECHANISM
                    CHOICE?      0
```

** Feasible Design chart displayed **

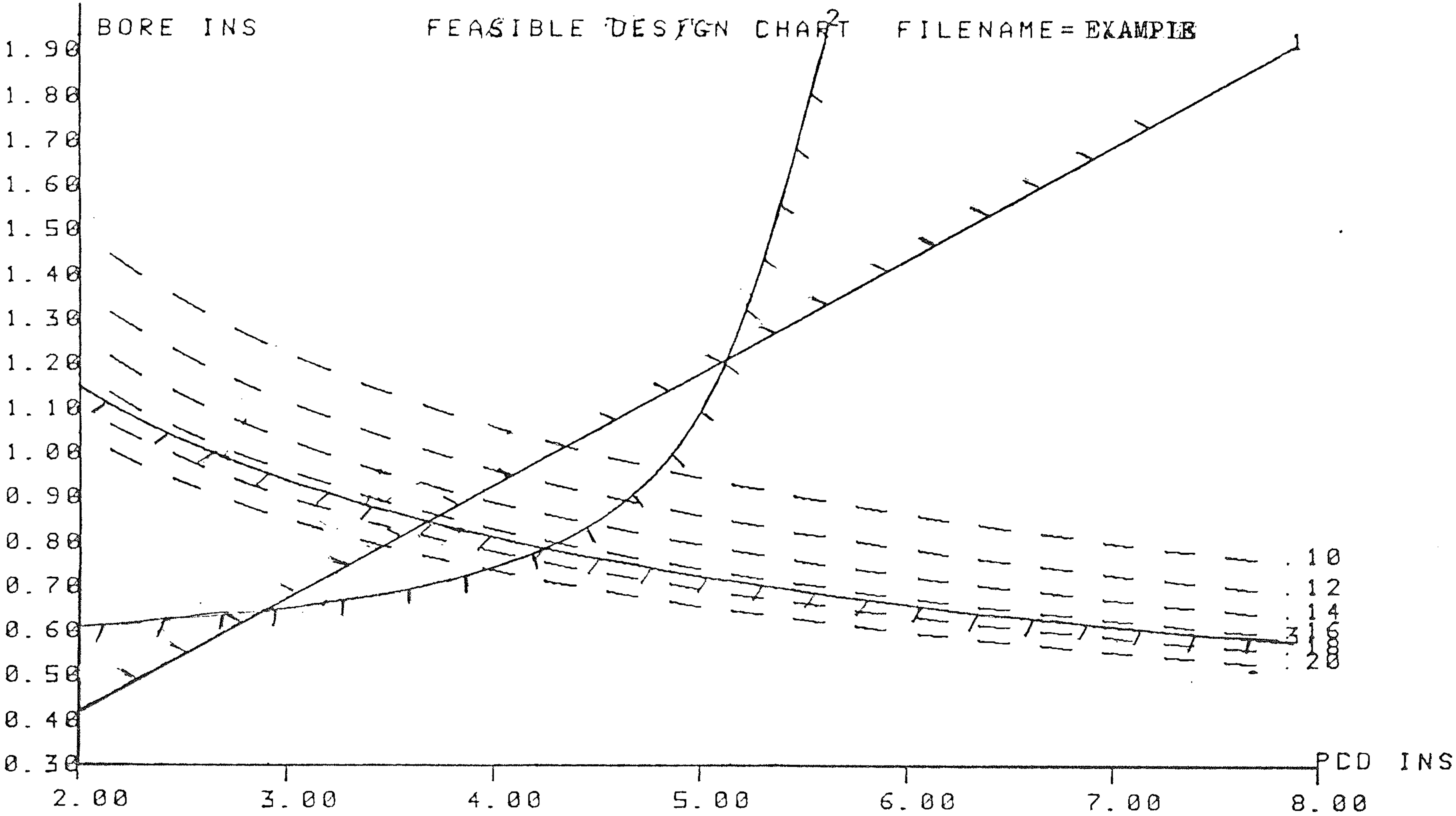


FIG. C.1d Chart produced by the design feasibility programme

```
WHICH JOURNAL WOULD YOU LIKE TO CONSIDER FIRST?
          0=NEITHER RESTRAINT
          1=SWASH END JOURNAL
          2=PORT PLATE END JOURNAL      2


          PORT PLATE END JOURNAL RESTRAINT



         ** Feasible Design chart displayed **



WHICH JOURNAL WOULD YOU LIKE TO CONSIDER FIRST?
          0=NEITHER RESTRAINT
          1=SWASH END JOURNAL
          2=PORT PLATE END JOURNAL      0


          JOURNAL RESTRAINTS PLOTTED


WHICH DESIGN RESTRAINT WOULD YOU LIKE TO PLOT?
          1=SLIPPER SEPARATION RESTRAINT
          2=CYLINDER SLOT HEAD LOSS RESTRAINT
          3=NECK STRESS RESTRAINT
          4=JOURNAL GEOMETRY RESTRAINTS
          5=BORE AND SLOT SEPARATION RESTRAINTS
          6=ROTOR INSIDE WALL THICKNESS RESTRAINT
        999=HELP!

               CHOICE?     5


BORE SEPARATION RESTRAINTS***************

     FOR THE ROTOR BLOCK

     WHAT IS THE DESIRED LOAD FACTOR
      FOR THE BORE SEPARATION CALCULATIONS? 2.0



         ** Feasible Design chart displayed **
```

```
WHICH DESIGN RESTRAINT WOULD YOU LIKE TO PLOT?
          1=SLIPPER SEPARATION RESTRAINT
          2=CYLINDER SLOT HEAD LOSS RESTRAINT
          3=NECK STRESS RESTRAINT
          4=JOURNAL GEOMETRY RESTRAINTS
          5=BORE AND SLOT SEPARATION RESTRAINTS
          6=ROTOR INSIDE WALL THICKNESS RESTRAINT
        999=HELP!

               CHOICE?      6


ROTOR INSIDE WALL THICKNESS RESTRAINT**********

   FOR THE ROTOR BLOCK

     WHAT IS THE DESIRED LOAD FACTOR
     FOR THE ROTOR INSIDE WALL STRESS CALCULATIONS? 2.0


        ** Feasible Design chart displayed **


WHICH DESIGN RESTRAINT WOULD YOU LIKE TO PLOT?
          1=SLIPPER SEPARATION RESTRAINT
          2=CYLINDER SLOT HEAD LOSS RESTRAINT
          3=NECK STRESS RESTRAINT
          4=JOURNAL GEOMETRY RESTRAINTS
          5=BORE AND SLOT SEPARATION RESTRAINTS
          6=ROTOR INSIDE WALL THICKNESS RESTRAINT
        999=HELP!

               CHOICE?      999


PLEASE ENTER ONE OF THE FOLLOWING:-


     1=I WISH TO ABANDON THE PROGRAMME
     2=I WISH TO RE-COMMENCE THE PROGRAMME
     3=I WISH TO BEGIN STAGE TWO OF THE DESIGN
     4=I WISH TO ALTER THE CHART SIZE

               CHOICE?      3
```

```
PLEASE TYPE:-
          CHOSEN SWASH ANGLE          15
          CHOSEN PISTON P.C.D.  INS? 4.0
          CHOSEN PISTON BORE  INS?    .875

THIS CORRESPONDS TO A FLOW CAPACITY OF       5.800   CIR

IS THIS OK?
                                                                  ##Y

ANGLE SUBTENDED BY BORE =      25.27
          IS THIS OK?
                                                                  ##Y



READY FOR STAGE 2****************
$
```

```
RUN /DESPRO

AXIAL PISTON PUMP DESIGN PROGRAMME
          STAGE 2

WHICH DESIGN FILE DO YOU WISH TO USE?     EXAMPLE


THE DESIGN THAT YOU HAVE CHOSEN FROM STAGE ONE IS:
               PISTON NUMBER=     9.00000
               PISTON PCD(INS)=      4.00000 ?
                                                               ##Y
               PISTON BORE(INS)=       0.87500 ?
                                                               ##Y
               SWASH ANGLE=      15.00000 ?
                                                               ##Y
THIS CORRES PONDS TO A FLOW CAPACITY OF     5.8000  CIR

     DO YOU WISH TO CONTINUE?
                                                               ##Y



     PISTON GEOMETRY*****

PISTON LENGTH=     2.39059 INS
BORE LENGTH=     2.61926 INS
UNSUPPORTED LENGTH=     0.90309 INS

BEARING SELECTION:-
WHAT IS THE BEARING INLET TEMPERATURE? 80



PP END JOURNAL BEARING DESIGN
JOURNAL THICKNESS DECIDED BY FLEXIBILITY CRITERION

MAXIMUM ALLOWED DIAMETER IS      2.32895 INS
MINIMUM ALLOWED DIAMETER IS      1.29440 INS
PLEASE CHOOSE A DIAMETER 2.0

DO YOU WANT TO CALL THE BEARING DESIGN PACKAGE?
                                                               ##N
```

```
SW END JOURNAL BEARING DESIGN
JOURNAL THICKNESS DECIDED BY OVALITY CRITERION
  PLEASE CHOOSE SWASH ARRANGEMENT:-
          0=SWIVEL MECHANISM
          1=WEDGE TYPE MECHANISM
               CHOICE?     0

MAXIMUM ALLOWED DIAMETER IS      2.21044 INS
MINIMUM ALLOWED DIAMETER IS      1.37970 INS
PLEASE CHOOSE A DIAMETER 2.0

DO YOU WANT TO CALL THE BEARING DESIGN PACKAGE?
                                                           ##N

     DO YOU WISH TO REPEAT THE BEARING DESIGN SECTION?
                                                           ##N

PLEASE TYPE:-
LENGTH CHOSEN FOR PP END BEARING?  1.0
LENGTH CHOSEN FOR SW END BEARING?  1.0

     DIAMETRAL CLEARANCES
          FOR PP END BEARING?  .003
          FOR SW END BEARING?  .003




PLEASE TYPE:-

         M-FACTOR?      1.95

RATIO OF INNER TO OUTER LAND WIDTHS? .95


     PORTPLATE GEOMETRY*****

OUTER LAND O/R=      2.10498 INS
OUTER LAND I/R=      1.94107 INS
INNER LAND O/R=      1.62143 INS
INNER LAND I/R=      1.46571INS
PORTPLATE I/R=     1.06000 INS

DO YOU WISH TO CHOOSE THE LAND RADII?
                                                           ##N
```

```
ROTOR O/D CALCULATION**
     WHAT IS THE DESIRED LOAD FACTOR
     FOR THIS CALCULATION?  2.0

     WHAT IS THE DESIRED APPROX RATIO
       PADS AREA:TOTAL PISTON AREA
          NORMAL VALUE APPROX 1.0          ? 1.0

 ROTOR O/D DEFINED BY REQIRED PAD AREA


     RUNNING GEAR GEOMETRY*****

ROTOR BLOCK I.D.=       0.96250 INS
ROTOR BLOCK O.D.=       5.25806INS

               IS THIS OK?
                                                           ##Y

DO YOU WANT A ROUGH SKETCH DRAWING?
                                                           ##Y
```

** Sketch of the Pump displayed **
(See fig. 10.6)

```
END OF STAGE 2**********
$
```

```
RUN /BEARIN


*****BEARING DESIGN PACKAGE*****
THIS PACKAGE AIDS IN THE SELECTION OF BEARINGS

PLEASE CHOOSE UNITS:-
               0=IMPERIAL
               1=METRIC
                    CHOICE?      0


WHAT IS THE BEARING LOAD?     2000

WHAT IS THE PUMP SPEED?       2500

BEARING INLET TEMPERATURE?(C)    80

          IS THIS CORRECT?
                                                              ##Y


PLEASE CHOOSE AN OIL FROM THE FOLLOWING LIST:
               1=TELLUS 15
               2=TELLUS 27
               3=TELLUS 41
               4=TELLUS 72

                    CHOICE NO.?     22\\2

SELECT A BEARING DIAMETER?    2.0


     BEARING CALCULATIONS PROCEEDING*****


          ** Bearing Design chart displayed **
             (See fig. 6.5)


DO YOU WISH TO ALTER THE DIAMETER OR CHANGE OIL?
                                                              ##N
$
```

```
RUN /FLEXIB


WHAT IS THE DESIGN FILE NAME?     EXAMPLE


USE IMPERIAL UNITS PLEASE.
NO. OF ENDS TO BE CONSIDERED?      2

NO. OF SECTIONS FOR 1ST (FP) END? 1
NO. OF SECTIONS FOR 2ND (SW) END? 2



LENGTH OF CENTRE SECTION? 3.0

BLOCK FLEXIBILITIES REQUIRED?
                                                                  ##Y


                END NO.    1
SECT   1 LGTH=1.0  O/D=2.2   I/D=2.0    APPL LOAD=1000

                END NO.    2
SECT   1 LGTH=.7   O/D=2.5   I/D=2.0    APPL LOAD=0
SECT   2 LGTH=1.0  O/D=2.2   I/D=2.0    APPL LOAD=2000
```

** Cylinder Block Deflection curve displayed **
(See fig. 10.3)

```
LLAMDA1=   29.670E-09

LLAMDA2-3=   21.346E-09
$
```

```
RUN /PERPRO


CALCULATION OF FILM THICKNESS AND ATTITUDE FOR
VALVE PLATES OF AXIAL PISTON PUMPS



PLEASE CHOOSE UNITS:-
          0=IMPERIAL
          1=METRIC      ?

0


DO YOU WISH TO RECALCULATE THE PAD DATA?
                                                                  ##Y


RATIO OF PAD INSIDE TO OUTSIDE RADIUS?   .8
NUMBER OF PADS?                          18
RATIO OF SLOT ANGLE TO SLOT+PAD ANGLE?   .1

DO YOU WISH TO ALTER THESE VALUES?
                                                                  ##N


WHICH FILE DO YOU WISH TO USE?     EXAMPLE
```

```
PLEASE TYPE THE FOLLOWING:-
          PORT PLATE DATA*****


          INNER LAND

     INSIDE RADIUS=                   1.46571 ?
                                                                 ##Y
     OUTSIDE RADIUS=                  1.62143 ?
                                                                 ##Y


          OUTER LAND

     INSIDE RADIUS=                   1.94107 ?
                                                                 ##Y
     OUTSIDE RADIUS=                  2.10498 ?
                                                                 ##Y
     PAD OUTSIDE DIAMETER=            5.25806 ?
                                                                 ##Y
     ANGLE BETWEEN PORTS=             0.00000 ?
                                                                 ##N
   NEW VALUE? 40


          PUMP DATA*****
     PISTON BORE=                     0.87500 ?
                                                                 ##Y
     PISTON PCD=                      4.00000 ?
                                                                 ##Y
     NUMBER OF PISTONS=               9.00000 ?
                                                                 ##Y
     CENTRAL SPRING LOAD=             0.00000 ?
                                                                 ##N
   NEW VALUE?100


     COMBINED FLEXIBILITIES*****

     LLAMDA1=         29.670E-09 ?
                                                                 ##Y
     LLAMDA2=         21.346E-09 ?
                                                                 ##Y
     LLAMDA3=         21.346E-09 ?
                                                                 ##Y


          PUMP BEARING DATA*****

ENTER THE FOLLOWING DISTANCES:-
SW. CENTRE TO INSIDE EDGE SW. BEARING?         1.42249 ?
                                                                 ##Y
SW. CENTRE TO INSIDE EDGE PP. BEARING?         3.82410 ?
                                                                 ##Y
```

```
          SWASH BEARING

     DIAMETER=                          2.00000 ?
                                                                 ##Y
     LENGTH=                            1.00000 ?
                                                                 ##Y
     DIAMETRAL CLEARANCE=               0.00300 ?
                                                                 ##Y

          PORT PLATE BEARING

     DIAMETER=                          2.00000 ?
                                                                 ##Y
     LENGTH=                            1.00000 ?
                                                                 ##Y
     DIAMETRAL CLEARANCE=               0.00300 ?
                                                                 ##Y

DO YOU WISH TO ALTER THE GEOMETRY?
                                                                 ##N


          OPERATING CONDITIONS*****

TYPE OF UNIT:-
          0=PUMP
          1=MOTOR ?      0

PRESSURE IN TOP PORT=          5000

PRESSURE IN BOTTOM PORT=        200

SWASH ANGLE  DEGREES=          15

ROTATIONAL SPEED  RPM
     -VE FOR ANTICLOCKWISE
     +VE FOR CLOCKWISE
   LOOKING DOWN ON PORTPLATE? 2500



          OIL SELECTION*****


PLEASE CHOOSE AN OIL FROM THE FOLLOWING LIST:
               1=TELLUS 15
               2=TELLUS 27
               3=TELLUS 41
               4=TELLUS 72

                    CHOICE NO.?      2
```

```
EFFECTIVE BEARING TEMPERATURE= 100

EFFECTIVE PADS TEMPERATURE=    100


DO YOU WISH TO ALTER THE OPERATING CONDITIONS?
                                                            ##N
DO YOU WANT THE RESULTS LISTING(1) OR FLOTTING(0) 0
```

** Performance chart displayed **
(See fig. 6.6)

```
DO YOU WANT TO SEE THE CLEARANCES?
                                                            ##Y
  FOR WHICH TILT?.7
```

** Clearances displayed **

```
CLEARANCES FOR OTHER TILT?
                                                            ##N
DO YOU WANT TO SEE THE RESULTS AGAIN?
                                                            ##N
DO YOU WISH TO ALTER THE OPERATING CONDITIONS?
                                                            ##N
DO YOU WISH TO ALTER THE PUMP GEOMETRY?
                                                            ##N

   END OF PROGRAMME**********
$
```

APPENDIX D

EXAMPLE OF THE C.A.D.S. USER-DOCUMENTATION

C.A.D.S.

COMPUTER AIDED DESIGN SYSTEM

- DESIGNERS REFERENCE GUIDE.

A. Clarke
April 1977

CONTENTS

SUMMARY

This report is intended as a brief guide to the Computer Aided Design System which is being implemented on the PDP 11/34 computer. The information given should be sufficient to enable you to become familiar with the system and its uses. You may then want to become familiar with individual programmes before using them in earnest, these are covered by the separate programme description reports.

Once you are completely familiar with the programmes, you might wish to explore further possibilities, for instance, you might wish to write or suggest further programmes for the system. These situations are naturally beyond the scope of this report but are covered by other I.S.V.R. and C.H.L. reports.

COMPUTER AIDED DESIGN SYSTEM (C.A.D.S.) - DESIGNERS REFERENCE GUIDE

1.0. INTRODUCTION.

The aim of this report is to discribe the design system which is being implemented on the PDP11/34 computer and to explain its purpose. The report is directed at potential users and clearly shows them how to drive the system.

The programmes described are those to be implemented in the first stage and are primarily concerned with information retrieved and pump running gear design. As time goes on, further programmes will be written into the system.

By and large, the basis for the programmes is established theory and essentially, the only new aspect is the method of presentation which is more rapid and systematic. But a clearer description of the technical aspects is given in the separate programme descriptions. In this report we will simply consider the structure of the system and how it should be used.

Notation:- In order to clarify the examples given in this report, a simple convention is used to depict text which is displayed on the design terminal.

i) Messages which are displayed by the computer are underlined.

ii) Square brackets are used to signify that the designer should type a message or word relevant to his own needs. e.g. LIST [file name].

iii) ∇ denotes a compulsory space.

Other conventions are explained as they arise.

2.0. THE DESIGN SYSTEM.

The computer aided design system is not intended to automate the design process, but rather to aid the designer by providing a systematic basis for design and reducing the effort involved in many of the design calculations.

Needless to say, the programmes cannot take account of all design considerations, in most cases only the fundamentals are considered. Therefore, this design system can really only be useful provided that you understand the limitations of the underlying theory and the way in which the programme uses this theory. For this reason you are advised to read the separate programme description before you try to run a particular programme. (The documentation provided in this report gives only a brief description of the purpose of each programme).

Sections 4. and 5. of this report deal with the two different aspects of the design system. These are information retrieval and design itself. Although these are described in separate sections they both form an integral part of the design system. The general structure of the system is shown in figure i).

If you are unfamiliar with the design terminal, then it will probably be necessary to read section 3 of this report before using the design terminal.

Once you are familiar with the system, then sections 4. and 5. will form a useful reference source.

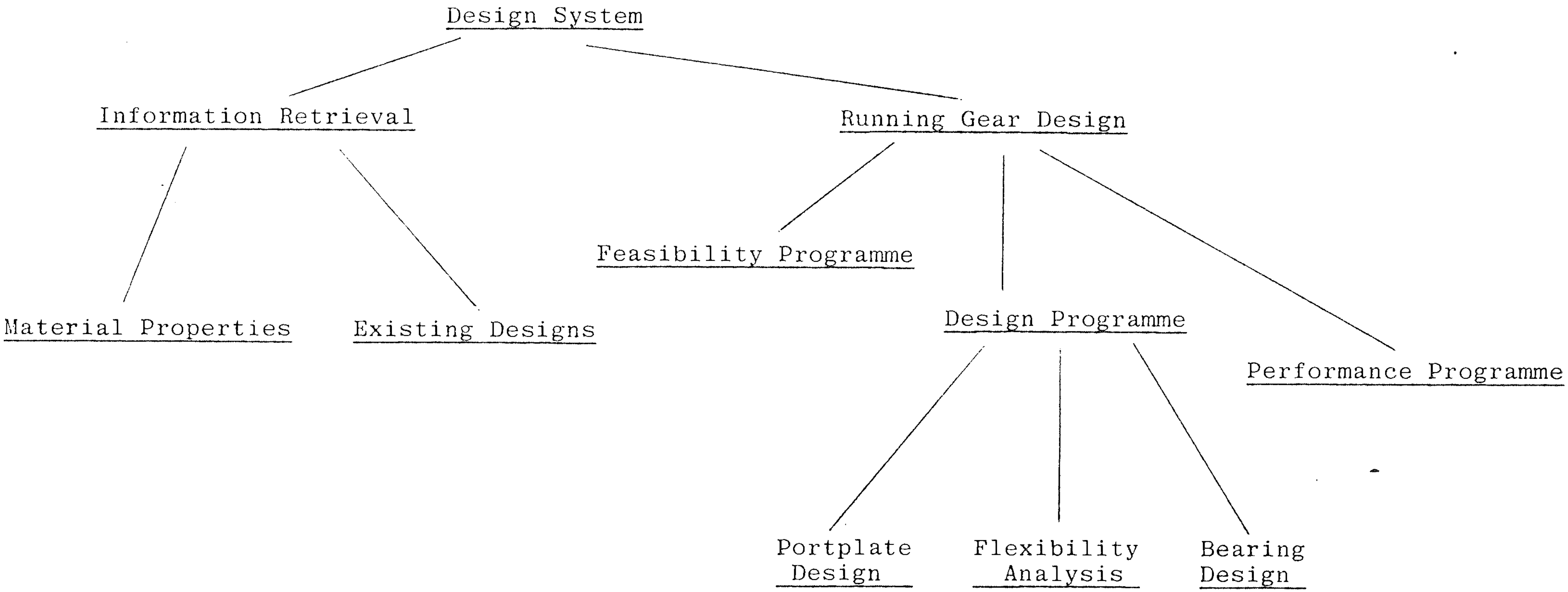
3.0. USING THE DESIGN TERMINAL.

3.1. Communication with the Computer.

The design terminal is the means by which you communicate with the computer.

If the conversation is under programme control, i.e.if a programme is being run normally, then the communication is straightforward. Usually a "?" will signify that you may reply to the computer.

FIGURE (i) STRUCTURE OF THE DESIGN SYSTEM



Example:-

PLEASE TYPE THE NUMBER OF PISTONS? 9 (R)

The (R) above shows that the user has pressed the carriage return key after pressing the number "9".

However, in all other circumstances, the computer will only listen to you if it is waiting for a response from you. This is signified by a "$" which the computer displays on the terminal. There are two ways in which such a "$" might appear on the screen:-

i) When the computer finishes a task, then it will display a "$".

ii) If you interrupt the computer by pressing the "BREAK" key, then computation will immediately cease and a "$" will be displayed.

Once the "$" has been displayed, then the computer will wait for you to type a further command.

Thus, the "BREAK" key gives you basic control of the computer. You can use it in conjunction with the other commands described in the next sections to achieve a number of objectives.

The symbol (BR) will be used to signify the "BREAK" key.

3.2. Beginning a Design Session.

Before you can begin a design session, you must first introduce yourself to the computer by "logging in".

To do this you should follow the following sequence:-

(BR)	First press the "BREAK" key to obtain the "$"
$ USE (R)	Next type USE followed by "carriage return".
IDENTIFICATION NO? [Code No.] (R)	You must then enter your code number and again press "carriage return".

(You will be given a code number before you first use the system).

If the response "ALREADY IN USE" is displayed by the computer then it means that the terminal is already being used (or that the previous user has forgotten to terminate his session).

Otherwise, the computer will first display any general information which might be useful to you, followed by the "$". You may then continue with your next instruction.

3.3. Correcting Typing Errors.

Pressing the "carriage return" key tells the computer that you have finished typing your instruction. Thus, you may correct a line of text that you have typed provided you have not pressed the "carriage return" key. (If you have pressed this key, the computer will have already received your incorrect instruction).

Provided you have not pressed "carriage return", the following two methods of correction are available:-

i) Press "RUBOUT" to backspace one character. This will be displayed on the screen as "\".

Example:-

```
$ UBE\\SE          (R)
```

The message USE will be sent to the computer.

ii) Press "LINE FEED" to cancel the whole of the present line. The line can then be completely re-typed.

Example:-

```
$ OSE              (LF)
  USE              (R)
```

The message USE will be sent to the computer.

3.4. Basic Commands.

The following commands are those which you are most likely to need when using the design system. They may only be issued once the $ has been displayed:-

i) ABORT. This is used in conjunction with the "BREAK" key in order to abort a programme which is currently running. This might be useful if you feel that you are making no progress with a programme and you wish to terminate it immediately. However, if this method of termination is used, the programme will have to be re-run from the beginning.

Example:-

```
BR
$ ABORT        R
$
```

ii) HELP. This command runs the programme "HELP" which is intended to help users to understand and use the computer system. The information which you can obtain using this programme is almost identical to that presented in the I.S.V.R.* report.

The programme can be used as a reference source while you are actually running a programme, when used in this way, you should follow this sequence:-

```
BR
$ HELP        R
```

---

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University of Southampton.

You will then be given a choice of alternative forms of help. When you have discovered what you wanted to know you may press "carriage return" to return to your original position in the programme which you interrupted.

ii) LIST. This command is used for listing files. Files are used for storing all information in the computer. The files which will be of most use to you will be described in the next section.

Example:-

```
  $ LIST ∇[file name]  Ⓡ
```

iv) RUN. This command is used to initiate execution of a programme or job. The programmes which will be of most use to you will be described in the next sections.

Example:-

```
     $ RUN ∇/[programme name]   Ⓡ
  or $ RUN ∇ [job name]         Ⓡ
```

3.5. Terminating a design session.

At the end of a design session you should "log out" so that other people can then use the design terminal. You may do this as follows:-

```
$QUIT   Ⓡ
```

4.0. INFORMATION RETRIEVAL.

The information retrieval system allows you to obtain information on materials and existing pump designs. Naturally, such information may also be referenced internally by the design programmes. However, in this section we will explain how you can obtain this information directly.

4.1. Pump Design Information.

Information on each existing design is stored in a design file. Before information on any pump can be obtained, you must know this file name. By and large, the file names directly describe the pump or motor in question e.g. SIZE10P.DES is the file name for the Size 10 pump. However, to check which is the correct file name you should consult the designer's index. This index contains the most common pumps, motors, and transmissions and their file names. In order to display this index on the design terminal you must list the appropriate file as follows:-

```
    $ LIST ▽ DESIGNS        Ⓡ
```

where DESIGNS is the file which contains the index of designs.

Once you know the file name, you can obtain the information by running the "Pump Access Programme":-

```
    $ RUN ▽/PAP             Ⓡ
```

You will then be asked to type the pump file name and then asked to specify what information you wish to see. When you have seen the relevant information, you may exit from the programme and return to the "waiting" state, i.e. a "$" will be displayed.

4.2. Material Information.

You can obtain information on metals and fluids using the "Metal Properties Access Programme" or the "Fluid Properties Access Programme".

You may run these programmes as follows:-

```
    $ RUN▽/MPAP             Ⓡ
and $ RUN▽/FPAP             Ⓡ
```

You will then be able to choose the appropriate metal or fluid from the list displayed, and then select which properties you wish to obtain. When you have seen the relevant information, you may exit from the programme and return to the "waiting" state.

5.0. PUMP DESIGN.

Pump design is accomplished using a number of programmes. The main programmes currently available are shown in figure i). Each programme references a pump design file or pump data file. (Pump data files are those which contain information on prototype or experimental designs. Unlike the design files they may be altered by the designer during the course of a design session. Pump data files are distinguished by the extension .DAC at the end of the file name. i.e. SIZE1OP.DES would be a pump design file. SIZE1OP.DAC would be a pump data file).

Hence, the design programmes may find information on any chosen design and use this in the design calculations.

The design suite can be split into three stages:-

i) The feasibility analysis.

ii) The design stage.

iii) The performance analysis.

If a new model is being designed then these three stages will be pursued in succession. However, for other applications it is possible that stage i), ii) or iii) above may be run in isolation.

These three stages are now described in more detail.

5.1. Stage I: Feasibility Programme (FESPRO).

This programme allows you to assess the feasibility of satisfying a given design specification. The computer will display a design chart which shows clearly the effect of a number of basic constraints on your choice of bore, pitch circle diameter and swash angle. The programme will also create a pump data file which you can use later in stage II or III for further design work.

The feasibility programme can be initiated as follows:-

```
$ RUN∇/FESPRO
```

5.2. Stage II : Design Programme (DESPRO).

This programme allows you to develop the consistent design which you conceived in stage I. You will be asked to make sufficient decisions to define the overall layout of the design. This scheme layout will then be sketched on the design terminal by the computer.

Next the flexibility of the cylinder block of this design will be calculated, and finally the design information will be written out to a pump data file, ready to be used in stage III .

The design programme can be initiated as follows:-

```
$ RUN∇/DESPRO
```

This design programme consists of a large number of sections which are executed in succession. Some of these sections, which deal with specific aspects of pump design (e.g. journal bearing design, portplate design) are useful in their own right. They may, for instance, be useful in part re-design, or modification of existing designs. For this reason, the design programme has been constructed so that these sections can be used as stand alone programmes. At the moment, three such programmes are available for stand alone use. These are concerned with journal bearing design, portplate design and determination of cylinder block flexibilities.

5.2.1. Bearing design programme.

This programme helps you to choose an adequate bearing configuration for a pump. Given the operating conditions and geometric constraints, the computer will show on a design chart which combinations of diametral clearance and L/D ratio will be acceptable for a chosen oil and oil inlet temperature. You may run this stand alone package as follows:-

```
$ RUN∇/BEARIN
```

5.2.2. Portplate Design Package.

In its present form, this programme allows you to determine the sealing land radii using information on the total land width required, the ratio of the two land widths, and the portplate balance factor. At a later date, the programme will be made more versatile and may sketch a drawing of the portplate.

You may run this package as follows:-

```
$ RUN∇/PPLATE
```

5.2.3. Block flexibility package.

You may use this package to estimate the flexibility of a given pump cylinder block. The flexibilities are expressed in terms of the angle between the block face and the normal to the bearing centre line. However, in addition to these flexibilities (which are required by the stage III programme), the programme also draws for you a deflection curve of the cylinder block centre line. Incidentally, although produced with cylinder blocks in mind, you can also use this programme for other components of similar geometries, for instance, the drive shaft.

This package may be run as follows:-

```
$ RUN∇/FLEXIB
```

5.3. Stage III. Pump performance programme. (PERPRO)

This programme predicts the attitude of the cylinder block relative to the portplate when the specified pump is running at specified operating conditions. Hence, this programme helps you to rapidly assess the effect on pump performance of slight alterations to pump geometry. The results are once again displayed on a suitable design chart.

This programme can be initiated as follows:-

```
$ RUN∇/PERPRO
```

Notes.

i) It is important to remember that the programmes described should be used with insight if useful results are to be obtained. For this reason, it is important that you read the separate programme descriptions before attempting to run a programme. These are contained in separate reports. (See appendix B*).

ii) A useful summary of the programmes in the design system is given in appendix A*

APPENDIX A* - INDEX OF DESIGN SYSTEM PROGRAMMES

PROGRAMME	DESCRIPTION	REPORT SECTION
Information Retrieval		
PAP	To access a pump design or data file	4.2
MPAP	To access information on a particular metal	4.2
FPAP	TO access information on a particular fluid	4.2
Pump Design		
FESPRO	To determine the feasibility of satisfying a particular pump specification	5.1
DESPRO	To produce a scheme layout of a consistent design	5.2
BEARIN	To help in the design of journal bearings	5.2.1
PPLATE	To help in the design of portplates	5.2.2
FLEXIB	To determine the flexibility of a cylinder block	5.2.3
PERPRO	To predict the performance of a specified design	5.3

FILE	DESCRIPTION	SECTION
DESIGNS	Index of current design files	4.1

APPENDIX B* - LIST OF C.A.D.S. REPORTS.

i) C.A.D.S. - Designers reference guide.

ii) C.A.D.S. - Description of information retrieval system.

iii) C.A.D.S. - Description of Design feasibility programme.

iv) C.A.D.S. - Description of Design programmes.

v) C.A.D.S. - Description of Pump Performance programme.

APPENDIX C*- USE OF JOBS TO RUN PROGRAMMES.

The programmes described in this report are intended to be run interactively; while the programmes are being run, the maximum time between your pressing the "carriage return" key and receiving a response is rarely more than 30 seconds and is usually only a second or so. However, depending on how long it takes you to find a suitable design solution, you might spend up to an hour at the terminal at a time. In some cases you might be certain of what replies you will make to most of or all of the questions. You might even be certain of how many times and in which order you wish to run various programmes.

In these circumstances the concept of a JOB is useful. This not only allows you to build the programmes into a given sequence, but also allows you to anticipate some or all of the questions.

As the demand arises, it is possible that certain "standard" jobs will be written into the system. Alternatively, you may wish to construct your own. If this is the case you will find a further description of the job system in the I.S.V.R. report "A handbook edition of the programme Help".

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