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Expert Group Meeting on the Development of Engineering Design Capabilities in Developing Countries

Vienna 11-15 May 1970

SOME THOUGHTS ON THE CREATIVE ASPECTS OF ENGINEERING DESIGN 1/

by

B.W. Turner
Chartered Engineer
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Dunchurch, Warwickshire
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The rapid technological growth achieved in the developed countries has demanded more and more creative capabilities with faster and faster reaction times. Completely new facets of endeavour have sprung into being as a result of scientific and engineering creativity - cryogenics, nucleonics, oceanography, space and communications technology. All these fields have demanded huge national expenditure and great creative effort. Clearly every country needs to foster and nurture creativity and this is exceptionally true for all developing countries. The relationship between science, technology and engineering is important and must be understood before considering engineering design, and some discussion on this aspect is given. But the paper is particularly concerned with the creative aspects of engineering design, and after tracing the translation process of going from an idea through to hardware, attempts to identify some of the abilities required within the total design process.

Some of the current methods being used to identify, select and develop creative engineering designers are then discussed together with some of the more recent aids to creativity. These include systematic design methods, morphological analysis and operational research, etc.

The impact of education and training of creative designers is considered in some detail and suggestions for improvement are given. Finally, the necessity for establishing the correct working environment by proper management and organization is set out.

The paper also contains seven appendices giving details of the Fundamental Design Method, a Survey of Engineering Creativity recently carried out, and copious references to work on engineering creativity.

Recommendations and conclusions are given showing how the suggestions put forward in the paper could be applied to developing countries with the help of UNIDO. It is stressed, however, that the acquiring of engineering design ability takes time and that there are no short cut methods by which a developing country can build up capable and confident design teams. Indigenous designers must be educated and trained with their countries' needs in view, if they are to reduce the production gap between affluent and emergent nations.

SOME THOUGHTS ON THE CREATIVE ASPECTS OF ENGINEERING DESIGN

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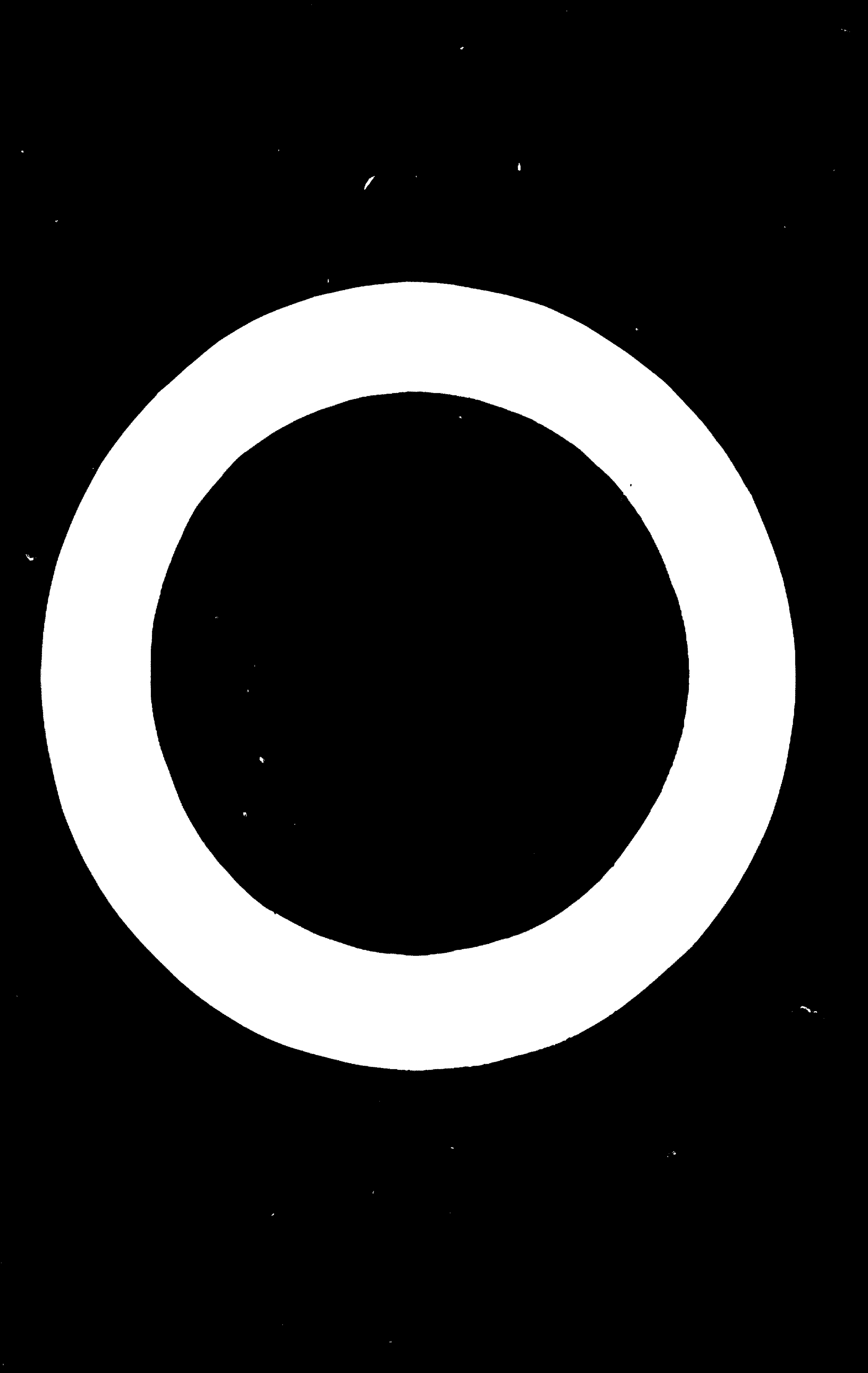
PREFACE

Every nation today needs to foster and nurture creativity, and this is especially true for developing countries. Since engineers are concerned with providing artifacts to improve the harnessing of nature for purposeful ends, it follows that productivity in engineering is vitally important. Creativity may be looked upon as an ability to produce new results from nature. Indeed, creativity is the prime mover of all human progress. In industry creativity needs to be applied everywhere but particularly in the design area.

The good designer is the creator par excellence. How can he be selected, developed and motivated to produce creative work? Is the industrial scene detrimental to creative people, and what type of environment and leadership is best suited to achieve creativity? These and other questions about creativity are very searching and difficult to answer. Much research is now being conducted into creativity but more is required, especially in engineering.

The national climate has a bearing on creativity as is evidenced when emergencies occur. World War II saw vast technological creativity from radar, jet engines and atomic power to penicillin and plastics. Tradition and Government policies can also help or stifle creative efforts. It is not the intention to discuss these latter aspects of creativity in this report except in so far as they impinge on engineering design creativity.



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SOME THOUGHTS ON
THE CREATIVE ASPECTS OF ENGINEERING

1. Introduction

When one looks for a definition of creativity there is almost a bewildering array of statements. Dr.E. de Bono prefers to use the term 'lateral thinking' to creativity(1). Others talk about innovation and invention. The term invention has at least three separate meanings, first it may mean a contrived object, second the mental processes involved in contriving, and thirdly, the ability to evolve a novel scheme or object, the latter is generally called inventiveness. Innovation is generally used when change occurs by applying something new. It really concerns the process of applying or installing some novel feature.

However, even allowing for the use of these differing terms there still remains the argument about the same term being used in the arts and sciences. Is creativity in sculpture or painting different from creativity in engineering design? Much research is being conducted today on this topic and evidence so far suggests that the same processes are involved in both activities.(2)(3)

Creativity in engineering is generally depicted in terms of an engineering product or its development at one end of a spectrum, but at the other end it may well be in terms of its aesthetic beauty, as with a suspension bridge. It will be shown later both these extremes of view are part of the whole.

One further word needs to be defined, and that is discovery. Discovery means to apprehend or expose to view, hence discovery preceeds invention. Science is concerned with the discovery of knowledge relative to the unchanging laws of nature. It has to do with acquisition of knowledge, whereas technology seeks to use the knowledge discovered to useful ends. It is an unfortunate occurrence in the history of mankind that the time gap between discovery and application has often been long, e.g. utilisation of the observation that vapour rises from boiling water to its application in the steam engine. On the other hand, Michael Faraday's discovery of electromagnetic induction led to working dynamos being introduced within a few years.

Often inventions lead to new discoveries and so a chain reaction is set up producing new thinking. Indeed, most of man's social, economic and technical systems have been built up by a synthesis of various inventions and creative leaps.

However, in looking at all these statements one is struck by the underlying fact that creativity and invention presupposes existing knowledge. To be creative requires a rearrangement of already known knowledge. This rearrangement demands a mental jump to break through existing thought patterns. All human beings have self organising memory systems leading to certain basic processes. The human mind stores information in patterns (concepts). The stimulation of creativity concerns the problem of breaking out of these conventional patterns. If certain concepts are fixed it requires faith and courage to break out e.g. Marconi and his wireless experiment. When he proved the possibility of long range broadcasting there already existed an accepted theory that such a process was impossible.

Perhaps creativity in engineering design may be considered to be the bringing into being of a new and useful combination of existing elements. As Lewis[4] has pointed out this fits many historical cases including Whittle's work on jet propulsion. He created a new power plant by combining two already existing elements, namely, the gas turbine and the reaction of propelling jets.

2. The Need for Creativity in the Design Process

Returning for a moment to science and technology, we have already indicated the interrelationship between these two activities. These can be seen more clearly in the form of the diagram in Figure No.1. Where the circle depicting science concerns the discovery of knowledge about nature, while the circle depicting technology deals with the application of this body of knowledge to the needs of mankind. The social, technical and economic situation at any instant creates a demand of one kind or another This demand may be met by new organisations of systems or sub-systems, or new administrations, or the production of new artifacts. These all require careful design. Engineering, therefore, concerns the application of the laws of science and the 'know-how' of technology, along what may be called the design line. The design line is depicted in Figure No.2., and does not cover research and development. However, these will often be required to refine or produce new knowledge and also to validate design ideas. However, design can only meet demand in the economic environment obtaining at the time. Established technology has to be made compatible with the economic atmosphere of demand and profit. Engineering design is the link between science and technology. It translates knowledge into useful hardware economically. Design is the heart of engineering and has to be considered in its entirety. It cannot be dissected into a split function activity,nor can engineering design today be confined to one man, it is a corporate activity. Design of a jet aircraft or high speed diesel engine demands considerable teams of designers. This brings into focus further problems concerning creativity. How is creativity to be fostered in a team as opposed to an individual?

Before looking at this aspect it is necessary to consider again the full range of engineering design activity. Figure No.3. endeavours to show the span of concern in design, at one end we have new product design and at the other modified product design. In between there is the partial new product design. It is important to recognise that every product is part of a system which may be automatic, semi-automatic, or human operated. Thus a domestic appliance has to fit into an existing energy distribution system, an aircraft into a transport system, and so on. Too often engineering design is considered in isolation from the system into which it is to fit. The aesthetic, ergonomic and technical aspects differ in priority according to the type of product or system concerned. For a new domestic appliance aesthetic appeal will be vital, but for a new guided weapon technical and ergonomic aspects will be most important. Most manufacturing enterprises make their profit from the modified product design by applying progressive improvements. These design evolutions may allow a firm to survive for a considerable period of time, depending upon competition. But ultimately survival is more and more concerned with the introduction of new products and processes. Hence the importance of creativity. Looked at in another way, there is a need in most industries for both an Athenian and a Tutonic approach to their overall work. Figure No.4 illustrates this point. Here the lefthand side of the diagram shows the familiar build up of a feasibility study aided by research and development work. Such studies lead to a technical solution. Real design now has to take place. The technical 'ideas' have to be turned into geometric form and creative design takes place. In all this process creativity is required. For this purpose more of an Athenian approach is necessary where uninhibited questioning, cross questioning and argument can take place. Once, however, the design is formulated precise instructions for production or construction have to be issued. Here a much more disciplined approach is required, as with conventional product work, where modifications to meet customers' requirements are required. Here a tutonic approach should be applied to ensure that accurate detailed production instructions are issued, which do not have to be continually altered and corrected. On the righthand side the design is applied to applications and iteration takes place between development and delineation to produce a prototype or mock-up. Finally, detailed manufacturing instructions have to be prepared and issued. This does not mean that there is no creativity involved in the more traditonal engineering work, but it is not of the same order as on the other side.

Returning to the design line, Figure No.2., it is possible to identify ten discrete steps as the design process takes place. First it is necessary to accept the problem situation - this means that an enterprise has to be prepared to accept a risk situation if they accept a contract or tender for one. The next step is to identify the main problem and sub-problems. This can be a most arduous task requiring careful interrogation of customer or client and other bodies. The identified problem has them to be specified and good engineering design depnds upon the accuracy of this statement. Well has E. Matchett described design as being:

> 'The optimum solution to the sum of the true needs of a particular set of circumstances.'

The design process then continues with the generation of possible alternative solutions. Here creativity comes fully into play as ideas are brought forward by a team of designers. It is in this phase of the work that a number of design methods have become available, in an endeavour to stimulate freer unstructured thinking. Some of these will be described later.

After examination and application of such techniques the best solution taking into account all the constraints and reconciliations that have to be made, is chosen, and detail design is commenced. Manufacture and assembly take place as the process continues and feedback takes place on a continuous basis. These iterations will inevitably have repercussions on the design process, which moves forward cyclically. In fact, design is extended into manufacture and test. In the test and inspection phase designers have the chance of seeing their creations in operation and last moment adjustment may be made. If the object designed requires erection and construction at some site then this may be looked upon as the extension of production. Finally, handover to the customer of the product and/or its system takes place, which, in turn, alters the environment in some way. As movement is made along the design line so the scope for making changes diminishes. Figure No.5 illustrates this point. Hence when considering creativity in engineering design we are primarily concerned with area 'A' in Figure No.3, and the first three stages of Figure No.5. While Figure No.2 also sets out some of the intellectual skills and abilities associated with the various phases of the design line.

Any country wishing to maintain an economic advantage will need to consider very carefully these areas and concentrate on obtaining maximum creativity to meet their major needs. Obviously the particular needs will depend upon the state of development of the country under consideration. If this is accepted it follows that selection of those who have creative ability and the development of these people is of paramount importance.

3. Selection and Development of Creative People

The underlying feature of creativity in engineering design is the fact that the new design produces an artifact that is different from, and better than its forerunners. Creative engineering has a definite aim or goal which is achieved by combining old and new ideas in unusual ways. However, it may not involve any new ideas, but simply using old ideas in new ways. Perhaps Edison had the latter in mind when he said:

'Invention is 1% inspiration and 99% perspiration.'

Luck also seems to play its part, for accidental creativity does occur and serendipity has been coined to cover this aspect. However, it is probably true to say that a prepared mind is required to grab hold of the happy accident. Creativity is a conscious act which cannot be performed vicariously, or imposed by opportunity, and in engineering there is generally a well identified need.

Can creative individuals be identified? Do they have peculiar mannerisms, personailities, temperaments or characters? For years people have considered creativity to be a gift which some were endowed with. Research now seems to indicate that the amount of creativity in the general population is distributed in the same way as other human aptitudes.[1] If this is so can it be measured, or are there any predictions or tests which could be applied? Much work is still being done in this area, but results are not yet conclusive.

Recent surveys have indicated some of the factors which seem to concern creativity in engineers[5]. In particular, R.J. Perry's work is used.[6] His aim was to provide some general information on the background of aero-engineers and to determine aspects of their work or their approach to that work that could be connected with creativity. A summary of the main results is given in Appendix No. 11. Two points worthy of note are the high value placed on drawing and sketching and the low weighting given to mathematics by these particular engineers.

3:1 A Method of Selection

In order to select engineering graduates who might make good design engineers, some exercises were conducted at Dunchurch Lodge,* Warwickshire, when the present writer was Principal. About 50 graduates who had taken degrees in varying disciplines were assembled at the Centre and divided into groups of six. They were presented with certain basic material, such as some drawing pins, cartridge paper, chalk, string, cotton reels, adhesive tape, etc. Each group had exactly the same amount of each material. They were then asked to build a crane in model form which was to provide the maximum lift height for a 1 lb bag of lead shot. Each group was observed and from time to time, a member of each group was called for an interview while the remainder carried on with their design.

One group's effort can be seen in Figure No. 6(a), while a group at work can be seen in the same illustration, at (b). The observer's reports were interesting and a typical example of one is given in Appendix No.III. Subsequent tests have revealed that the

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* The Staff Training Centre of the English Electric Company Ltd. Now Dunchurch Industrial Staff Training Centre. (DISC)

observers' evaluations were correct and that Mr. X was significantly superior to his peers with regard to spatial ability, a factor of some importance in engineering creativity.(7) (see Appendix No.[illegible]) The ideational fluency of the graduates was noted, e.g. who thought of what and the number of ideas brought up by each member of the group, and the quality of each idea. Note that this was not a solo effort but a corporate one simulating in microcosm the real industrial engineering design situation. Subsequent analysis revealed that there was little co-relation between the class of university degree obtained and the creativity of the candidate, a fact already noted by Lewis(4)

3:2 A Method of Development

Numerous writers have emphasised that there are certain environmental features which can help or hinder creativity, and this has already been alluded to when discussing Figure No.4. Even a very gifted person requires a stimulating environment, including freedom from distractions which can deflect a train of thought. Management of such an area is not so easy for it must not be too authoritarian, but it must have a warm but demanding atmosphere with a high esprit de corps. This is why management of design is such an art. By poor management creativity can be stifled. One method that was used by English Electric to stimulate development of creativity in its engineering designers was to use the Engineering Employers' West of England Association's Fundamental Design Method course designed and run by E. Matchett. Altogether over 100 designers from the company have attended this course.

Essentially, the FDM approach concentrates on the designer's mind. It is based on the application of work and method study to the design process. Hitherto these techniques have been applied to investigating what people do rather than to how people think. It is a highly disciplined form of thinking which allows the individual to increase his awareness. It brings his thought processes out into the open, thereby making it easier to bring constructive criticism to bear. FDM causes a designer to think more logically and clearly about his work, questioning every move he makes. At every stage of the design,

P_1, P_2, P_3....... P_7, etc. (Figure No.7) assessment is made by a self interrogation process.

This requires that the designer be able to recognise the essential nature of his own thinking (T) at that moment in time, and also the essential nature and content of the control (C) (Figure No.7) which he is exercising. Thought in progress is thereby continually monitored and redirected. Such a possibility demands a new form of awareness which is only developed by practice. In addition, FDM trains designers to use various fundamental concepte regarding what essentially ought to be happening at any point in the design process.

One such concept is that of the total available dimensions, possessing six fundamental facts (See Figure No.7). For convenience, these various wavelengths of thought are often imagined as follows, each name being used as a definite catalyst to commence mental scanning and progression in depth in its area of the total spectrum:

(Need) ———	Meaning	——— (Reason)
Objective		Purpose
Form		Cause
Magnitude		Consequences
Standard		Effectiveness
(Time) ———	Media	——— (Space)
Occasion		Locality
Duration		Position
Frequency		Relation
Sequence		Environment
(Means) ———	Matter	——— (Method)
Men		Principle
Materials		Procedures
Machines		Priorities
Money		Performance

Hence the fundamental design method developed by E. Matchett concentrates on disciplining one's own thought and work. Mr. Matchett has described his method thus:[8]

'What a person has hitherto considered to be thinking is replaced by, or supplemented by, mental activities of a higher order. The differences are to be found not so much in the form of logic employed, but in the quality, in the content and in the modes and depths of mental activity.

Throughout an F.D.M. course every student works on a major practical project brought with him from his own company. The project tutorial repeatedly forces him to consider this project, and justify his own thoughts and actions in terms of basic abstractions. In addition, daily exercises, intimately geared to his own project require the student to produce answers in terms of 'the essence'. He puts forward considered propositions regarding such things as the items listed below:

1. The essential nature of a process that will provide the required solution.
2. The process refined into a definite strategy in which every element is expressed in terms of essentials.
3. The critical path that will maximise achievement while minimising resources committed.
4. The essential nature of the key problem, described in such a way that it stands out in relief.
5. The essential nature of any satisfactory solution. This exercise is usually completed long before any glimpse of the material form of the design is obtained.
6. The essence of the most important skill required for the success of the project.
7. The mental catalysts, directors and controls that one relies on, some of which are listed below. (Our thoughts and actions are highly patterned, though we are normally totally unaware of this).
8. The essential factors that caused the most important idea in the project to be conceived.

9. The essential positive and negative factors within the total environment (including one's inner world), that most influence current progress of the project.

10. The essential nature of those abilities, vital in one's normal work, which self study has helped one to understand. Also weakness and practical means of overcoming these.

Some Mental Catalysts, Directors and Controls used by those attending A Matchett Course are as follows:

Catalysts

Memories of past designs
Competitors' products
Deliberate doodling and day-dreaming
Single words with rich associations
Self-questioning
Basic forms and archetypal symbols
Biological analogies
Science fiction
Irritation, anger
Complete quietness
Deliberate distortion of existing ideas
Technical reading
Trying to describe what one is attempting

Mental Directors

Use of free association (private brainstorming)
Use of formal propositions
Critical analysis techniques
Formal logic
Scientific method
Statement of objectives
Definition of problem
Definition of major obstacles
Concepts of the structure of the design process
Strategies proved successful in the past
Systematic factorising and charting

Controls

Engineering fundamentals
The essential requirements
An appreciation of one's own mode of thinking
An appreciation of other people's view of decisions made
Analysis of feedback from results
Knowledge of the past history in some field
A clear vision of the design as a system within a system
Conscious standards of own progress and performance
Highly disciplined modes of thinking such as in F.O.W. theories and examples.

... Projects studied on an F.D.M. course frequently make use of a great variety of charting methods, matrixes and formal methods of displaying thoughts and decisions with all of their interactions, freedom and constraints. In the table below, for example, the effect of each item on all the others can be traced by illuminating each in turn.

TABLE X

Interaction of Parts in a Design Project

	Items affected by elimination							
Eliminate	Aircraft	Door	Hinge	Latch	Shear Device	Closure Device	Support Device	Operator
Hinge	No	Yes		No	No	Yes	Yes	Yes
Latch	No	Yes	No		No	Yes	No	Yes
Shear Device	No	Yes	No	No		No	No	No
Closure Device	No	Yes	No	No	No		No	Yes
Support Device	No	Yes	No	No	No	No		Yes

The main purpose of using such charts, materices, etc. on F.D.M. courses like that of defining the essence of problems using modes, is bound up with obtaining greater internal control over one's own thinking. In a very real sense, all of these devices serve as temporary mental crutches, which will be dispensed with, except for special purposes, once the necessary mental skills have developed.

Great achievement, of either an individual or a team, cannot always wait on the acquisition of further technical knowledge and management aids. The key factors are, more often than not, the level of individual skills and the precise way in which these are utilised in pursuing necessary objectives.

These in turn depend primarily upon the level of awareness and understanding, which can only be modified appreciably by a very careful analysis carried out by the individual himself.

The rewards of such analysis are many. A kind of deconditioning takes place, a person becomes progressively freed from his past biases and thought patterns; and also from his own self-image. Weaknesses in knowledge, attitude and skills become apparent, together with the possibilities of overcoming or compensating for them. As understanding develops, the threshold of consciousness is lowered so that there is a much greater awareness of the nature and significance of every move one makes. Gradually one learns to become, as it were, an accurate and independent observer, and later controller, of one's own thoughts. Further details of the FDM course have been supplied by Mr. E. Matchett, and are included in Appendix No.IV for completeness of this report.

Several evaluations have been made by the English Electric Staff Training Centre (now DISC), of these Matchett F.D.M. courses and their effect on designers. The report written on this evaluation is, of course, confidential to the Company (now GEC/AEI/EECo), and cannot for this reason, be given in toto. However, a summary of some of the main points as to the effect of the training and development of engineering designers is given in Appendix No.V, together with a personal report of one design engineer who attended the course, showing how it had helped him in his own design area.

Some Further Important Factors

In stimulating and developing creativity other factors need to be considered, for example, the traditional educational system and its time honoured pedagogic methods. Many have suggested that the formal educational process has negated against creative capabilities because the closely directed well-disciplined activity from kindergarten to university, has encouraged conformity and fear of stepping out of line.[9][10] With this comes a resistance to change. Thinking is channelled along a set route, using available information, being logical and sequential with justifications being made at each step. In other words, by traditional use of information the thinker has to be right at each step.

Said William James, 'Genius, in truth, means little more than the faculty of perceiving in an unhabitual way, or put in another way, 'Seeing what everybody else has seen but thinking what nobody else has thought'. In creative work jumps have to be taken, steps are left out. To obtain creative thought it is, therefore, necessary to break away from the normal habits of thought and leap up with imagination into the subconscious. See Figure No. 8. To develop imagination an attitude of day dreaming may be necessary - the mind has to free wheel. Besides providing the correct environment for this to happen there are a number of techniques which may be used and some of these will now be discussed.

4. Aids to Creativity - Some Problem Solving Methods

Sir Joshua Reynolds[11] said:

'Invention is little more than new combinations of those images which have been previously gathered and deposited in the memory. Nothing can be made of nothing, he who has laid up no material can produce no combinations'.

How then can these new combinations be brought to the conscious, examined and used? It is beginning to become apparent that there are roughly three levels of general problem-solving techniques which may be useful in this context:

a) **Algorithmic** - Here precise instructions may be set down and hence a computer may be used.

b) **Heuristic/strategic** - In this class general principles may be set out but with no detailed rules of play. A computer may be used but it is extremely difficult to arrange in most cases.

c) **Intuitive** - These cover a broad range with many degrees of uncertainty.

The latter in engineering design is often covered with the time honoured statement, 'We took a calculated risk here, but no one has ever seen the calculation!'

To make the best use of individual techniques it seems reasonable to arrange them into a suitable set of conceptual categories. S.A. Gregory[12] has suggested a matrix in three dimensions which consist of the following:

a) Urgency of Problem via Identification, viz:
   Breakdown, current competitive problem, market forecast; technological forecast in long range.

b) System level in terms of complexity, viz:
   Material; component; sub system; super system.

c) Stage of Development, viz:
   Fully optimised; evolved and needing current optimisation; known solution which needs improved alternatives.

Techniques may be viewed in this matrix with location according to their applicability. For example, those falling in the algorithmic (manual or computer), such as 'attribute listing' will be seen as a technique for dealing with the preparation of a specification for a design brief.[13] Similarly, all those techniques concerned with optimisation fall into this same area. Most design methods and well established textbook procedures and in the same category. With the strategic techniques, where it is difficult to computerise, the work study approach or questioning techniques may be seen in terms of system level and stage of development, while intutive methods may also be seen against the above three-dimensional structure.

Looking at the overall picture of engineering design methods a kaleidoscopic view can be seen in Figure No. 9. F.D.M. has already been discussed. The others vary from various systematic charting methods and decision trees to behavioural techniques, such as brainsterming and synectics.

In addition to the above there are other general methods which can be used to aid creativity, such as the scientific method, operational research and the exhaustive matrix.

4:1 The Scientific Method

This method consists of a circular process which starts with observations leading to a statement of the problem. It is a gathering phase where all the relevant information and significant data is assembled. The next step is the formulation of an hypothesis. Movement to this stage requires inductive reasoning. Induction moves from the particular to the general, thereby making possible an increase in information. Then follows the third stage, which requires deductive reasoning so that the consequences of the hypothesis may be tested. The creative step is in the formulation of an hypothesis or model. Validation of this step is generally by a controlled experiment which is observed, and these observations are then compared with the original observations. If this comparison is encouraging, the hypothesis may be tested again to determine whether it can predict results in new contexts. If, however, there are discrepancies, the hypothesis is modified until it can be applied to all cases. The hypothesis now becomes a theory or a law, and can be used to predict with certainty results when conditions similar to the original ones are in existance.

From the foregoing it can be seen that the circularity process is not unlike the design process itself. It is a characteristic of the design method that the problem to be solved is in connection with the fulfilment of some human satisfaction. This problem may be perceived as a result of market research or direct observation, or intuition. The next step is to generate as many alternative solution possibilities as can be handled with the resources available. This is like forming the hypothesis - a search for reasons for the occurence which were observed. This will probably be no one correct solution for all time. A good solution has to be found to the design problem by evaluation. Engineering design is further characterised by the absence of complete knowledge which is merely one aspect of the limited resources with which the engineer has to work. It follows that since knowledge and resources are limited someone has to take responsibility for outcomes. Here the critical decision is taken. The designer using all the knowledge, expert advice and experience available together with intuition makes a creative leap for which he will be responsible. Unlike the scientist, however, who can later modify his hypothesis, the engineering designer generally has to live with his design decision.

Returning to Figure No.1, for a moment, the diagram attempts to show the interaction between science and design. It is clear that in the industrial context where firms are science-based there will be extensive use of the scientific method in research and development departments.[14] Their work will often be found to impinge on design activities. Mainly this will be in the form of codifying existing knowledge found by others and formulating theories (hypothesis) and planning, designing and conducting experiments.

But the scientific method is also used in the industrial situation to increase productivity, hence the rise of work and method study, etc., with the consequent rise of management services and other departments to examine operational data critically to develop imporved ways of doing things.

Of direct relevance to design is the Kepner Tregoe approach to problem solving.[15] Here the scientific method is applied to problem analysis (PA). See Figure No.9, a logical series of steps to ascertain the cause of a deviation from an expected norm. Decision Analysis (DA) an analysis between alternative courses of action and Potential Problem Analysis (PPA) an analysis of the cause of future deviation from an unexpected norm. By going through the cycle of problem analysis, decision analysis, potential problem analysis, and demanding a written answer to the questions, What, Where, When, How much, How many, under the headings, 'is' and 'is not', it is possible to draw distinctions and changes may be investigated. From the changes the cause will then emerge.

4:2 Operational Research

An official definition of (OR) Operational Research is 'the attack of modern science on complex problems arising in the direction and management of large systems of men, machines, materials and money, in industry, business, government, and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors, such as chance and risk, with which to predict and compare the outcomes of alternative decisions.'

A typical example of the use of OR in design has been the development of AIDA 'Analysis of interconnected decision areas, Most systematic design methods are primarily used for analysis; they help to generate information about the engineering requirements. But as more and more information is obtained there comes a time when a designer has to synthesise a solution from a large number of factors, each one of which has its own set of constraints, etc. The traditional engineering approach has been to split up the problem into a series of sub-problems, but with many sophisticated advanced technologies, the sub-problems are so interdependent that this becomes very difficult.

The basis of AIDA is that of an OR approach which leads to an option analysis. Just as critical path analysis provides a language for discussing inter-relationships of timing of different design activities, so AIDA is a language in which inter-relationships of decision and the questions of compatibility at each stage of the design activity can be discussed.

For very large projects like a supersonic aircraft, or a power station there will be several design areas where a number of alternative designs are possible. See Figure No.9. under AIDA, where each decision area is ringed and each option within these areas is marked by an 'X'. Then a map of the decisions can be drawn out where links between options express incompatibility. Clearly with very large systems the number of options can be large, and a computer is required to provide the best options to choose in each area.

AIDA is most useful in the early definition stage where the views of those outside the engineering design process can be taken into account early enough to influence the design. Thus, in motor car design (a consumer durable product, of the modified product design type. See Figure No.3), it will be the marketing department and long range planning people who are particularly concerned in helping to develop concepts, as well as production people.

Yet another method of design to encourage creative thought is the exhaustive matrix.

4:3 Morphological Analysis

The term was coined by Frits Zwicky[10]. He first suggested that if one studies the features of any object they can be set into an hypothetical morphological box, such that no pigeon-hole in the box contains more than one feature. Some boxes may be empty. Zwicky pointed out that by going through this kind of ordered analysis it was possible not only to characterise fully a given object of some kind, but also it was possible to set out the list of characteristics which would be expected to hold for any object likely to fall within the same class.

From this set of general characteristics it became possible by permutation and combination to work out likely characteristics of objects which do not yet exist, but which might be capable of achievement.

This approach makes use of a matrix to relate all the conceivable features or functions required of the solution to all the possible means of obtaining them. Thus, the Zwicky morphological approach focuses on the 'form' of design, whereas the Matchett Fundamental Design Method focuses on the 'mind' of the designer.

For example, when designing a domestic appliance the designer would list vertically on his matrix paramters such as form, size, material, etc. On the horizontal axis of the matrix he would then extend a list of means of achievement - these would be parameter steps. The matrix is extended until the designer's imagination runs out. It is then necessary to establish criteria to judge possible solutions, and these may be in quantitative and qualitative terms. Finally, the field of possible solutions is obtained by applying these criteria and exercising personal judgement, again, for large matrices a computer may be of help.

4.4 Main Characteristics of Systematic Design Methods

In general when applying systematic design methods,[5][17][13] of which there are a bewildering number today, it will be noted that they:

a) Help the designer to cover the design problem area exhaustively

b) Provide a mechanical method to assist the designer's mind to handle massive operations (possibly with a computer).

c) The creative leap, or stage is recognised to be a different kind of activity and provision is made for this.

d) Separate imaginative ideas from their logical judgement (deferred evaluation).

e) Present a clear and easily followed record of the design process.

f) Allow many designers to take part simultaneously in the design process.

g) Cause the design to revolve by logical predetermined stages. It imposes a disciplins on the design team.

h) Makes explicit the distribution of effort between retrieval and generation of design information.

Out of all these factors (c) is the most important for, if no provision is made for a creative leap, designers will be forced into a purely mechanistic approach to the work, which will amost inevitably be sterile. Too much concern with mechanical technique could detract from the real creative phase of engineering design work.

4.5 Organised Group Methods

The most potent techniques for idea generation utilise the concept of free association. The two best known, brainstorming and synectics, were both worked out initially in terms of group activity. This has great advantages, since any group can draw on wider ranges of schemata and associations than any one individual.

a) Brainstorming

Brainstorming has several operational aspects and these have been described by A.F. Osborn.[9] A small group is brought together to discuss ideas to solve a problem which is directly stated. In this group there must be no critical discussion and no strong leadership attempts. Ideas are generated until the discussion runs down. The discussion is recorded. After the session the various ideas put forward are evaluated by some suitable person or group.

In addition to this freewheeling generation of ideas Osborn proposes a number of ways of manipulating ideas. This we may call a kit of 'perturbation' techniques. These perturbation techniques may, in fact, be traced back historically at least to Lord Bacon. They include the suggestions: adaption; modification; substitution: modification we may interpret further as: change of magnitude: addition, subtraction (minify or omit), multiplication (magnify or duplicate): rearrangement: change of sequence, reversal, combination (unite or purposes), and so on.

b) Synectics

Synectics employs an interdisciplinary group of which only the leader at first knows the problem. This he leads up to in a very general way by trying to state notions having a relationship to what may be required. He attempts to get his group to suggest ways of expressing this general notion by examples. Very often analogies of some kind are used: sometimes metaphorical statements. Thus, 'a flame' is a 'ghostly presence'. Biological analogies tend to be favoured.

c) Kepner Tregoe

A third group method is the application of the Kepner Tregoe[15] method previously mentioned. Here the charting system is employed by a design group. Undoubtedly this scientific method of approach yields benefits in terms of time to find a solution. Limited evaluations taken at Dunchurch Lodge showed, in the case of three groups of designers that the group that had been exposed to the KT method and used it, were the only group to come up with a realistic design solution within one day, the time scale set. The method is particularly valuable for analysing the reasons for the malfunctioning of designs and, therefore, applies to the latter stages of the design process.

5. The Impact on Education and Training

There is much talk concerning changes to education in all countries, and engineering education is no exception. Some of the features that have been mentioned in this report have importance for both professional educationalists and industrial managements. The changing nature of our societies with increasing emphasis being placed on international responsibilities, and the raising of the standard of living for developing countries, makes it essential to encourage the maximum utilisation of creative talents. From the ability to use created wealth to further creative solutions to extensive social problems is one of the most pressing human predicaments today. The limitations are social, political and economic, the resources are dedicated creative people who can use science and engineering to find solutions. To use Von Karman's pithy remark we need 'The scientists to explore what is, and the engineers to create what has never been'.

This being the case, does our existing engineering educational system*

* The author's comments here concern the UK engineering educational system, since he is not so familiar with those in other countries.

allow for maximum creativity? In the main, the present system does turn out good research and development engineers, but not good design and production engineers*. It will be noted that from Appendix No. II that less than a quarter of the design engineers questioned held a degree. Most industrialists would support the view that their best designers do not come from the higher educational university system. This means that the majority of engineering designers cannot qualify as professional engineers. Great efforts are being made by the Institution of Mechanical Engineers through their Education Committee to try and persuade the Council of Engineering Institutions (C.E.I.) to provide another route for designers to become chartered engineers. (C.Eng)(21)(22)

To be successful and achieve a better engineering design output from the existing higher educational system a new approach is necessary. A possibility here is the 'back-to-front' teaching method.

5:1 A Back-to-Front Teaching Approach

Here a course would be designed to attract those school leavers who were disenchanted with sterile analysis and who had shown some creative ability, with a concern for economic and social factors. The back-to-front approach starts with the concrete and moves backwards to the abstract. An understanding of the engineering involved in some current hardware would first be studied, showing the macroscopic needs of the system; this would lead into the subsystems, general elements, and thence to the microscopic, dealing with the structure of matter. Engineering taught in this way could be made interesting, vital and relevant to society's needs.

The teaching plan for such a course could be approached more from the art of the practical engineer, the creative person. It can best be illustrated by one of the author's diagrams taken from a previous paper(23) Figure No. 10.

Here the identified human need is expressed in current hardware form - it could be a car, a mechanical digger, or a power station. In this

* It is probably true to say that the US is better at education for production.

case a mechanical digger as a typical example of plant engineering hardware has been used. Some alternative ways of removing subsoil from place to place would be discussed, such as blasintg, blowing, dragging, eroding, etc. The economic and hsitorical factors would be introduced, e.g. building of caterpillar trucks or the introduction of bulldozers, and by these means the student could be introduced to a variety of sub needs via existing hardware. The maintenance factors and ergonomic requirements for safe operation, etc. could be studied. The digger could then be broken down into discrete units - engine, steering, transmission, etc. - to enable the study of specifics; and the historical study of the transmission systems could include new developments and, by these, the concepts of the laws of motion and energy transformation introduced. These would in turn lead to the general laws of system elements and from them excursions could be made, where required, into the molecular and atomic systems. Moreover, as progression proceeds towards the right of the synoptic illustration, design and manufacturing considerations may be introduced.

In conventional teaching of engineering it is usual to concentrate on the fundamental laws first, and to practice analysis. In this new approach an effort would be made to bring ideas together first by synthesis, and to introduce the student to utilisation factors.

5:2 A Design/Production Teaching Approach

Another approach is to use a project design method.[24] Here an opportunity is given to students to attempt design and manufacturing exercises, which are conducted in circumstances as closely resembling normal industrial ones as possible. Groups of 6 to 8 undergraduates are presented with the problem of making some piece of equipment which is preferably required for some laboratory or works. The job has to be completed within the framework of time and costs. No instruction or help is provided unless it is sought, and consequently, the group discovers at first hand the importance of organisation, division of labour, delegation of responsibility, assessment of resources, problems of communication, estimating, progrees, planning and accountancy, in addition to putting to use the manual skills of drawing,machining and fitting. Appendix No. VI gives part of a report by an undergraduate working on a design-and-build project at the MTC*.

*MTC. Manufacturing Training Centre, Rugby, of the English Electric Co. Ltd.

In this connection it would pay some engineering educationalists to study how architects are educated and trained. For some time civil engineers have lamented the fact that architects have a poor appreciation of engineering matters, but it does appear that their design training has much to commend it. Too often engineering undergraduate education is research based, and the educators themselves are increasingly being recruited from the system. In fact the educational system becomes self devouring of its most successful candidates. Consequently they are without experience as engineers who have done design, or invented something, or who have had experience as entrepreneurs. Consequently the professors, lecturers and teachers have removed themselves from the social, economic and political problems of the day.

If Liam Hudson's research work(25) is correct it would appear that the products of arts faculties of our universities will, on the whole, be 'divergers', while engineering students appear to be 'convergers'. By 'divergers' Liam Hudson means those who are better at open ended tests, but weaker at I.Q. tests. A 'converger', on the other hand is the reverse and tends to perform best on intelligence tests. Although the implication that divergers are creative and convergers are not has not been fully proven, it certainly appears that the majority of engineering university courses recruit from the convergers. Architects, on the other hand, are nearer the artists and are recruited from the divergers. On looking at architectural courses today, one is struck by the stress placed on, and the time allocated to, practising design skills. There are abstract exercises, limited objective design exercises, and total design projects, as well as 'live' projects. They all require an independence of approach and a heterodoxy in analysing solutions.

It is perhaps worth noting that academic research in architecture is of recent origin and only indulged in by a few. Also, the subject of architecture has not developed academically like, say, medicine or engineering. For this reason it is mainly taught by those who practice, rather than those who research into architecture. This is very different from the majority of engineering teaching, where the higher instruction is arranged to be given by those who have carried out original research into some abstruse engineering aspect for which they have been granted a higher degree. For this, and other reasons, it seems questionable whether original research is a good qualification for those who teach designers. Architects do not make or construct anything, whereas mechanical engineers do, and must, therefore, understand manipulative and assembly processes. Perhaps the comparison here is better represented by the medical profession where students have, of necessity, to help practice on live patients while, and before, qualifying. Engineers too need to practice and understand machining processes, etc. and know how things are m de. If creativity comes from a prepared mind then engineers could be trained better by having a walking-the-ward approach using industry as a laboraotry to teach future designers.

Whatever new methods are tried it is important that they encourage imagination, and inculcate habits of indenpendent thought and action. The present courses are biased toward effectively imparting knowledge with little opportunity to demonstrate the use of knowledge given.[26]

6. Company Management and Organisation for Creativity

Turning from the educational to the industrial scene there are a number of implications of time factors mentioned that warrant the concern of industrialists, who are always endeavouring to master a situation so that a profit is obtained from their energies.

One problem facing large industrial complexes is how they can foster entrepreneurship. Poor utilisation of scientists and engineers dogs the large concern where all too often, people are pressed into a standard mould.[27] The wedding of creative engineers and scientists with entrepreneurship produces striking innovations in a short time, as the new enterprises on Route 128 testify. Along the highway near Boston there is a string of new companies started by former employees of the Massachusetts Institute of Technology. The companies have been remarkably successful and have largely been formed by young men in their early thirties. They all had one feature in common, they were entrepreneurially minded and with an idea they were determined to convert into a product or service which they would offer to the market. M.I.T. studied more than 160 firms on Route 128 which had been formed by former M.I.T. employees.[28] It is significant that few of these enterprises had failed.

The reasons for this low mortality rate are not easily determined, but one given is the fact that since the companies are small it is much easier for individuals to experience stronger motivations to make a creative contribution and for this contribution to be recognised.

6:1 Working Environment

It is vital that management at all levels undertands how to use creative individuals. Certain traits of a creative person make it difficult for the conventional wisdom of a company's organisation to handle them very often they are impulsive, anti-establishment, non-conformist, have independence of judgement, and have a tendency to work with intense energy bursts followed by exhaustion. Humour must not be out of place for very often creative people are humerous. Also it seems to be a law of experience that creative people work best when set tight deadlines, and that they are not particularly stimulated by conditions of work, job security, pensions and the like. They are very much motivated by recognition and opportunity for achievement, and it is in this area that managers of engineering designers need to concentrate. As Herzberg has pointed out(29) conventional personnel policies have tended to concentrate on factors which are dissatisfiers rather than real motivators. Such factors, Herberg called, the hygiene factors, they are concerned with the environment in which the task is done, their theme is job context. They may not of themselves, create job interest, but when satisfactory they prevent frusttration setting in.

In order to improve a company's human creative resource more attention has to be paid to the real motivators, which are associated with job satisfaction, e.g. individual recognition and reward, interesting and challenging work, genuine responsibility, scope for individual advancement and growth, etc.

In this connection it is pathetic in British industry how the Council for Industrial Design (C.o.I.D.) will persist in giving Queen's awards to managing directors of companies and not to real designers. Seven Queen's awards granted to Marconi Ltd., is hardly likely to motivate design teams or individual designers. It is to be hoped that the proposed National Design Council which may link engineering design with industrial design will correct this situation. Much better awards are given by the Engineering Materials and Design Association.* The 1969 Class I Award was made to Mr. L.A. Hopkins for his original design of the Hoverbed. (See Appendix No. VII).

Managers of design teams will need to see that adequate recognition and rewards are granted to their individual designers, so that they are motivated to achieve better performances. They will have to recognise that many creative people are indiosyncratic and need careful managing if their creativity is to be encouraged, but they should not be coddled.

There seems to be some evidence to suggest that age is an advantage with creative people. Maybe the mature man or woman has developed the willpower and persistence required for creative achievement. For research work, however surveys have indicated saddle shaped curves with twin peaks of achievement separated by 10 to 15 years.(32)

6:2 Stimulating Creativity

While recognition is paramount there are certain stimulations which can aid creative efforts. Many of these have already been discussed. Greater understanding of the mental processes involved are required, and Matchett's work and others needs applying in design offices, one aspect seems clear and that is, that it is essential to allow engineering designers 'time off' to study some of the new systematic methods and to become acquainted with the application of group techniques.

However, there are considerable depressants in the socio-technical systems of the West. The tax system favours manipulators rather than creators. The blistering tax system to maintain a Welfare State in the U.K., the antitrust laws in the U.S., and the emergency antitrust regulations in the Common Market mitigate against innovative sucess. Perhaps stimulation of creativity could best be achieved by some highly visible rewards like financial recognition, without tax to those who demonstrate their ability. This point might certainly be considered by the developing countries whose bureaucracies are not yet fully established.

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* 33 - 39, Bowling Green Lane, London, E.C.1.

6:3 **Recruiting Design Staff**

Intelligence does not seem to correlate with creativity as E. de Bono has pointed out[1] 'the charm of lateral thinking is that it is an exciting search for the simplicity of a good idea and that it is open to everyone, since it is not dependent on sheer intelligence.' Vertical thinking, as he has called conventional logic thinking, has high probability, but lateral thinking has low-probability with sideways thinking, Nevertheless, it appears that a certain threshold of intelligence may be required by creative people depending upon the culture in which they operate. Guilford[30] has attempted a measurement of creativity through hypothesis of apititude traits believed to be related to creativity. The five types of operation provided for by this concept represent the scope of all intellectual activity including, therefore, the quality measured as intelligence. His five types are cognition, memory, divergent production, convergent production and evaluation.

It seems clear that our present educational system puts a great emphasis on intelligence and intelligence testing, rather than on creative thinking. In industry creative people are required and therefore need identifying, placing, utilising and developing to the full. New approaches to the selection of engineering designers and their management seems an urgent and pressing problem. Some of the work by Jackson and Messick[31] may point the way to better testing for creativity.

In the developing countries it might be possible to set up educational systems which are designed to encourage and develop creative thinkers, rather than copy much of the present educational emphasis in the West which is geared to scholarship and accumulated past wisdom.

7. Special Note

7:1 Acknowledgements

In writing this note on Creativity the author is particularly grateful for help received from E. Matchett, R.R. Whitfield, S.A. Gregory, J.D. Monk and R.J. Perry. In particular for permission to publish Appendix IV by the West of England Employers' Association, which sets out the objectives of Mr. Matchett's courses.

The author also wishes to acknowledge his indebtedness to members of the C.E.I. Working Party Sub-committee, of whom he is a member. The C.E.I. Working Party on Creativity and the Engineer was set up in 1968 under the chairmanship of Mr. H.G. Conway.

7:2 C.E.I. Creativity Working Party

The history of the Working Party was given in the CME of May 1968 and is set out below for completeness.

Creativity and the Engineer

'Much has been written and talked about of late on preparing university graduates to meet the needs of industry. Most proposals involve the acceptance of graduates as they are, warts and all, and do not deal with alternative educational courses.

Why is it that the productivity of engineers, in terms of new ideas, varies so greatly? What is the influence of the educational process? The Institution considers it important to attempt to find an answer to these questions and has therefore established a Creativity Working Party under the chairmanship of the Past-President Mr. H.G. Conway.

Its terms of reference are to survey the existing scope and content of mechanical engineering training, both theoretical and practical, for professional engineers. It is to pay special regard to the extent to which the overall training of mechanical engineers, as at present carried out, tends to develop an analytical approach to engineering problems, instead of fostering the creative ability needed in designing and managing. The working party is to recommend changes to be made in order to remove weaknesses.

The preliminary survey may be undertaken by a small team of one or two engineers and a social scientists.

For the time being, creativity in engineers is defined as denoting:

> the ability to synthesise and evolve new and improved engineering configurations in the service of man. Essential elements for creativity are perception, imagination, and the ability to design and experiment. The relevant elements may exist in varying proportions in the make-up of the individual but, at least in mechanical engineering, perception and creative design are predominant. Creative design may range from the ability to evolve the overall conception of novel systems or machines to the ability to conceive better design of elements of machines or structures forming part of larger complexes devised by others. Both extremes are equally important.

As this problem is not confined to mechanical engineering, other members of CEI have been invited to collaborate. The Ministry of Technology has become an enthusiastic supporter of the investigation. The work is proceeding in two phases.

Phase 1 involves a literature survey and this is being undertaken by a member of the Working Party. Phase 2 will attempt to identify the characteristics which lead to creative work. The Working Party have in mind a survey of perhaps 500 individuals and a selection of organisations who are considered to be creative.

The Council has approved a grant of £1000 from the James Clayton Bequest Fund to support the investigation and there will be further assistance from the Ministry of Technology.

7:3 **Present Position**

Phase 1 as set out above is not complete and various publications will be issued in due course. Phase 2 is about to start with special studies being carried out in some British universities.

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APPENDIX NO. II

SURVEY OF ENGINEERING CREATIVITY

MAIN CONCLUSIONS FROM MR. R.J. PERRY'S PILOT SURVEY

1. Reason for Survey

The object of conducting the pilot study was to provide some general information on the background of aircraft engineers, and to determine aspects of their work or their approach to that work that could be connected with creativity. In this way it was hoped that the survey would help people to redefine and refine their ideas on creativity, and throw some light on how management could help to stimulate creative work.

2. Method of Survey

The survey was conducted by questionnaire and interview amongst approximately 8% of the relevant staff. It covered 127 people: 108 were asked to fill in a questionnaire and 99 completed questionnaires were returned : 19 people were interviewed.

3. Main Findings

a) Mean age of respondents was 31 - 35.

b) 50% went to grammar schools
3.5% went to public schools
46.5% went to secondary schools.

c) 23% held a 1st degree
3.5% held a higher degree
57% held and HNC or ONC*

d) Drawing was used occasionally or frequently by 70% and sketching by 98%.

e) High level mathematics was used rarely or occasionally by only 20%+

f) 40% of the respondents thought that no creative ability was needed for their present job, about 60% a fair or large amount. But only 19% thought they had no creative ability, 81% that they had at least a fair amount.

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* HNC = Higher National Certificate, ONC Ordinary National Certificate.

+ Low level mathematics is defined for this purpose as simple calculations or graphical integration, etc.

g) Logical thought was given as a source of creative thinking in 50% of the cases, flashes of insight or out-of-the-blue by the other half. More or less equal numbers of ideas came to individuals on their own, as to a man during discussion, but twice as many came at home as at work.

h) 32% stated that creativity encouragement came by thought brainstorming, 39% via rewards, 60% from acknowledgement.

4. <u>General Comments</u>

No hard and fast conclusions can be drawn from this survey, although the sample is adequate, no statistical correlations have been made. It does, however, pose certain questions and suggests that further studies are necessary. The importance of spatial ability - drawing and sketching (perspective and 2D) - the lack of use of high level mathematics. Motivation to do creative work seems to depend upon acknowledgment which lines up with Herzberg's work[9] It would appear that job enrichment by applying Herzberg's motivation/hygiene theory could benefit these designers.

APPENDIX NO. III

AN OBSERVER'S REPORT ON A GROUP CREATIVITY

A group of six engineering graduates were observed throughout one day. They were asked to design a model to lift a 1lb. bag of lead shot through the maximum height possible given certain resources.

The resources were:

Cartridge paper
Adhesive tape
Glue
Elastic bands
Paper clips, drawing pins,
Cotton reels,
String

Summary of Observations

1st Hour No one in the group could get going.
Side arguments occurred frequently.
One member then put forward a proposal.
This was immediately criticised.
Another member started to build on his own but was stopped by the rest of the group.

2nd Hour Group decided after two suggestions had been made to sketch out a tentative design and allocate parts of the work to certain members of the group.

Rough sketches were produced and small experiment completed.

3rd Hour Feverish activity took place to get a solution, and one member dominated the scene and ordered building to commence. The chosen solution failed to raise the lead satisfactorily.

4th Hour Modification was applied in the form of stiffness - it was noticeable that only one member attempted to do a calculation to justify any proposals.

The final 30 minutes were devoted to aesthetic aspects which had not been considered up till then.

The group did not win the prize or come second or third, but they had one feature which other groups did not have - that was a chart showing the progress of the design thoughts. They rejected a number of possible attractive solutions which were indicated on this chart.

APPENDIX NO. IV

The Objectives and Methods of F.D.M. Training

F.D.M. training is used by a Company as a means of obtaining appropriate further development of the capabilities of persons in responsible technical and managerial positions. This training helps a man to understand more precisely the real demands of his job, the strengths and weaknesses of his present approach, and the disciplines he can apply to improve his performance.

The whole emphasis of this advanced form of man-development is that of training by objectives. Such objectives are arrived at by a careful appraisal of the most urgent needs of the Company, the department and the individual. (The nature of such an assessment is outlined in documents D.09 and D.10).

The Philosophy of training by objectives implies that each man requires individual tuition during training, in order that he may have every opportunity of reaching his goals. It is important to realise that the objectives will be different in every case, and that it is therefore not possible to structure any two courses, or two learning experiences within the same course in the same way.

Each course, and each learning experience is structured in accordance with the particular detailed needs as they become apparent, largely on the initiative of the individual course member.

Experience gained over a number of years has shown that it is not possible to conveniently classify all of the kinds of objectives that can be successfully attained through Fundamental Design Method Training. The following are those which are most frequently found to be necessary:-

Perception

1) Highlight weaknesses in methods of exploiting physical laws and concepts.

2) Improve ability to recognise casual relationships and significant factors and modes of interaction with a complex system.

3) Improve ability to rise above one's immediate task to examine it from many different levels and viewpoints.

4) Improve ability to see particular technical and/or human problems in the context of the total circumstances.

5) Increase sensitivity to the strengths, weaknesses and feelings of others.

6) Improve ability to recognise the freedoms that are available in a situation that appears to be totally constrained.

7) Improve ability to assess the priorities in one's total activities.

8) Highlight possibilities for raising the total value of the work for which one is responsible.

9) Assess knowledge and skills required for the successful execution of a new project.

10) Improve ability to overcome the emotional attachment to an idea, in order to recognise its true worth.

11) Improve ability to learn much more from immediate and past experience.

12) Improve awareness of unnecessary constraints that one allows to control one's thinking, and of characteristic bias and patterning.

13) Improve awareness of the size and kind of job that one would ultimately be able to tackle effectively.

Initiative.

1) Improve ability to confidently move forward in uncertainty, without taking unnecessary risks.

2) Improve ability to analyse and learn from one's own actions and mistakes.

3) Improve ability to adapt and respond appropriately to the demands of new situations - both intellectually and emotionally.

4) Improve ability to rapidly change course when circumstances change or signal that the initial appreciation was in error.

5) Increase empathy with all aspects of the job, such that there is an enhanced sense of purpose.

6) Improve ability to more effectively discover and use information.

7) Improve ability to recognise and discard that learning and data which is no longer appropriate.

8) To acquire a convenient means of assessing and directing one's own mental growth.

9) To acquire the capability to develop any mental skill which becomes particularly important in one's working environment.

10) Increase ability to utilise present strengths.

11) To develop attitudes and values that enables one's energies and intellectual capabilities to be more profitably directed.

Approach.

1) Improve ability to think in terms of the real needs rather than to be too attracted by solutions based on familiar practices.

2) Improve ability to analyse past approaches in order to establish more efficient methods.

3) To become far more flexible in an approach to both technical and human problems.

4) To determine actions that can be taken to significantly raise the effectiveness of persons for whom one is responsible.

5) Improve ability to evolve appropriate plans for dealing with a situation rather than relying on habitual or standard approaches.

6) Improve expertise in the technical and commercial evaluation of an idea.

7) Improve ability to evaluate alternative solutions to complex problems.

8) To control the imagination so as to generate far more ideas in a given time.

9) To expand one's powers of vision to see more clearly the total implications of possible decisions.

10) To improve the standards of acceptability which one applies to one's own thought and actions.

11) Improve ability to easily discriminate between the form of an artefact or system and its essential nature.

12) To work with a greater understanding of the essential <u>structural</u> characteristics of situation, system and thought process.

13) To more easily obtain access to subconscious mental processes and materials, thus extending the areas over which deliberate disciplines can be exercised.

14) To acquire the ability to devise entirely new and very effective forms of controls to apply to one's thinking.

15) Improve efficiency and integrity of applying knowledge in the critical areas of one's work.

16) Improve ability to monitor and control the direction and contents of one's thinking at any time.

<u>Stature</u>

1) To be capable of carrying an increased work load and responsibility.

2) To possess increased competence and confidence in respect to vital areas of one's work (technical, administrative, managerial etc)

3) Ability to tackle more complex work which places greater demands on one's judgment, initiative, imaginative powers and overall sense of responsibility.

4) To be less dependent on external aids, standard techniques and other people.

5) Increase poise in discussions and negotiations with customers and various technical and commercial departments.

6) An understanding of oneself and others that permits a greater contribution to team work and more effective communication where different disciplines and personalities are involved.

7) Ability to change own role, policies, and management style in a way that will lead to increased effectiveness of one's group.

8) Overcome conflicts between personal aims beliefs and values and the demands and characterists of the work situation.

9) Improve ability to suppress fears and negative feelings at the outset of new and more demanding work.

10) A greater readiness to assess a situation coolly and objectively even when under pressure.

11) To make a continuous and creative adaptation and response to particular circumstances in which one finds oneself.

It is important to realise that the above are only given as examples of the kind of objectives towards which modern training can be directed. It is sensible for one individual to pursue only a few such objectives simultaneously, so that his efforts might be concentrated to obtain really worthwhile results. Other members of the same course can be directing their attention to a different nucleus of objectives without any person hindering another's progress.

In order that the character and significance of present day Fundamental Design Method training might be appreciated, it is necessary to draw attention to the difference between training by objectives and the teaching of a particular logical approach (for example the P.A.B.L.A. system of the United Kingdom Atomic Energy Authority, Aldermaston). Unnecessary conflict has arisen in the past through both course members and their management viewing F.D.M. as nothing more than a methodology. Many persons have attended earlier courses seeking some kind of magic formulae for designing and decision making. Yet on return to their Company the criteria on which the success of the training was judged was never whether one kind of methodology was used instead of another. It was invariably, and rightly, the extent to which the man had become more capable in his job and in his relations with other people in the working environment.

Over-concern to learn a formulae has sometimes diverted a person's attention from searching for whatever was most critical to him becoming more effective in his job. Our experience has shown that a major component in bringing about an improved performance is to prevent what seems to be a natural tendency to put the reasons for one's own inability to improve on to some thing, person or system, either within one's work situation or outside. Quite often these reasons have been linked to past as well as present circumstances. The "F.D.M. formulae" could become simply another support or tactic for refusing to discover and face up to the kind of changes that should be initiated by, <u>and within</u>, oneself.

By putting the emphasis of F.D.M. training on to <u>training by objectives</u>, anyone who now attends a course is left in no doubt as to what he is attempting to achieve, and what will be expected of him. The man is put in a position where he can analyse and overcome his own deficiencies, and those for which he is responsible. He is judged, and judges himself, on whether and to what extent he has managed to do so.

There is one skill which F.D.M. training helps to develop that provides the means of major and rapid developments in many others. This is the ability to monitor one's own thinking, as though observing any process which is instrumented for control purposes. The overall objective is to reach that stage of awareness and development when it becomes possible to apply appropriate disciplines to one's thinking <u>at any moment in time</u>. Each course member is expected to learn how <u>he</u> can design and apply the additional disciplines which his thinking requires, as and when they are needed. There is no longer the query whether or not an "F.D.M. formulae" is of any value. The only questions that are now asked are which kinds of mental activities need to be strengthened, and what actions must one take, on one's own initiative, to produce the necessary changes.

The course is much concerned with discovering a (unique) way of helping the individual course member to think about his thinking such that will bring about the required development. Over the years a body of knowledge has been built up of many different kinds of approaches, out of which have been distilled a number of fundamental concepts and basic modes of thinking. These are presented in ways that assist the course member with his particular task. Every effort is made to ensure that the man works from the basis of his own training objectives. By making a particular nucleus of training objectives the focal point for all his strivings the basic material is automatically selected and translated in accordance with these objectives. In other words the course material is seen only as a means to an end. It does not become an end in itself. Even more important, is the fact that the course material is continually related to the particular objectives. One does not first of all learn another subject, and only then begin to consider how it might be put to practical use.

The major characteristics of F.D.M. training which distinguish it from other methods of man development, are as follows:-

1) It is structured to change whatever mental skills, values and attitudes require improvement in a given working environment rather than being restricted to only certain of these (For example, interpersonal skills), or to teaching a technique for examining only certain aspects of a Company's activities or products.

2) The development is produced by direct analysis of the particular mental disciplines and the obstacles which are preventing improvement.

3) The person is required to search for and succinctly define what he has learned from his current experience and also from earlier experiences, and "critical incidents", which contain lessons that he had previously failed to recognise and exploit.

4) He is required to become objectively conscious of failures and weaknesses in the disciplines and controls which he characteristically exercises over those aspects of his thinking, and behaviour, that have a significant influence on his job achievement and performance.

5) The development is always built upon and around the individual's unique characteristics, and utilises any strengths which the man already possesses, to produce the required improvement in capability.

6) The development is brought about by the individual's own efforts rather than through group work. Throughout the training great care is taken to ensure a person need not disclose anything to his fellow course members - or to his tutor - that is of a private and personal nature, or which touches on aspects of commercial security.

7) The person is required to build up a real understanding of his work situation, systems, and personal disciplines in so far as these influence the improvement that is required. Much of the methodology of the course is concerned solely with producing such understanding.

8) To help to develop understanding, and to test that it is genuine, great stress is laid on producing models which reflect the essential structure of a situation, work system or personal skill.

9) The person learns how to use such models as concepts to direct and monitor his thought and behaviour at any moment in time. Also how to continually revise such concepts to include additional increments of understanding that come from subsequent experiences.

10) Once the person learns to consciously control his thinking in this way it is possible to learn more from all experience - both immediate and past. The realisation that such is possible has a major motivating and liberating effect.

11) F.D.M. teaching is built around a number of basic concepts which are exceedingly powerful once they are understood. One such concept is of three fundamental dimensions ("Media", "Meaning", and "Matter") which appear to structure the whole of creation - including any possible creation of man's. The three fundamental dimensions relate to each other in a triangular system, which has many recognisable levels within itself. Control of thought and action is described and considered in terms of this concept for a wide variety of purposes.

12) All of the fundamental concepts in F.D.M. teaching assist a person to obtain valuable insights across a whole spectrum of levels, including those which are of a highly personal nature. The depth to which an individual will wish to penetrate, and the rate at which he will wish to proceed, will naturally be different for every student. Such a comment would also apply to his total development following the training. Many factors, particularly those concerning the general Company climate and management attitude to the training, will influence such growth.

Prior to the completion of his F.D.M. training each course member is required to produce a programme for his own further development within his normal working environment. He is also required to decide what changes he wishes to implement in work systems, procedures, etc., which his analysis has shown to constrain achievement and performance, either his own or that of his group.

Unless there is a definite commitment of this kind, which is periodically reviewed and updated many of the possible benefits of the training are not realised. Training by objectives should lead quite naturally to management by objectives, with the person managing his own further development as an integral part of managing his day to day achievement and performance. The real significanc of F.D.M. training lies in the fact that it makes management by objectives a philosophy capable of realisation in practice. Self management is not possible beyond a certain point unless and until a person becomes vividly aware of all of the critical factors and obstacles which he has to learn to control, and until he has acquired the conceptual tools that enable him to deal with them.

APPENDIX NO.V

Some comments received during an evaluation debriefing session and critique on F.D.M. held at Dunchurch Lodge 6th March, 1969

The twelve points listed are not in any order of priority but most of them were brought out by three or four attenders at the session. There were 32 present for the whole day.

1. If F.D.M. is really to succeed it must be installed at the top first. (e.g. start with the design manager).
2. Some of the techniques are difficult to use and discussion is necessary. (see separate report at end of this appendix).
3. To be really effective it would be best to see two or three candidates from the same design office to get a 'cell' working with F.D.M.
4. F.D.M. taught by Matchett tends to destroy your self confidence, sometimes he does not always fill the void created and antagonism occurs. For other people he destroys to build up and they go back to their 'Baileywicks' on fire, but end up smouldering. Frustration sets in, hence the importance of (1) above.
5. There is a need for a continuing dialogue with Matchett if full success and impact of F.D.M. is to be made. Ideally recall courses and in-plant visits should be made by 'Matchettised' people, or Matchett himself to stimulate, guide and counsel.
6. The different set of constraints are applied when you return to your workplace. Must know how to handle these.
7. There has to be a willingness and wish to improve. Matchett process cannot be imposed on designers.
8. In many ways Matchett is his own worst enemy, he needs more skill in educational presentation. Pedagogic approaches of a new type are required. He tends to use a language of his own. Will have to learn to sell a concept and accelerate acceptance, if any benefit is to come in our lifetime. Not all representatives agreed on this latter point, since any work of this nature is bound to take time.
9. Matchett needs to humanise his message, he relies on abstract terms and is too far away from reality. He should pay more attention to his introduction to get people off to a good start.

10. The F.D.M. course for the older, experienced designer can be a dangerous experience. F.D.M. is a way of life, one candidate thought a short course in psychology would achieve the same success. Some type of pre-course filter should be designed.

11. F.D.M. helps to put creativity and the design process into perspective, and for individuals it lowers the threshold between the subconscious and the conscious. Like the Laser it gets your mental power into a narrow coherent beam. It improves the quality and speed of your thinking.

12. Propagation of F.D.M. within a design team is best achieved by having a converted 'cell' (see point (3) above), but individuals can evangelise by doing their job's better, this is difficult for some designers where large teams are employed and decisions are made by many people in the design area.

APPENDIX NO. V (CONT'D)

INDIVIDUAL

REPORT ON FUNDAMENTAL DESIGN METHOD

(Mr. 'Y' works in the design department of a business concerned with electrical switchgear)

I have divided the total gain I have received from the course into three main headings:

1. Improvements in self.
2. Improvements in dealing with people.
3. Tools provided by F.D.M.

1. Improvements in Self

More organised thinking.
Priorities in correct order.
Aware of one's capabilities; limitations and special knowledge.
Taken out of mental rut.
Not satisfied with something that works.
Able to stop at any moment and analyse position.
Awareness of the involvement of vision, knowledge and judgement in design.
Mental disciplines and controls which I have added or improved.

a) Controls Added

Stop jumping to conclusions.
Able to extract basic design requirements and analyse them.
Able to draw charts of strategy and see ultimate end clearly.
Able to investigate major factors before embarking on single path, which once started upon difficult to stop.
Able to analyse better (to resolve into smallest elements).
Able to stop and back check.
A more determined attitude against criticism of an idea.
To accept constructive criticism and make use of it.
Define between cause and effect.

b) Controls Improved

Stopped making snap judgements and rigidly adhering to them.
Able to attend and listen.
To create an essential path.
Control the feeling of fear and panic.
Control a conditioned outlook influenced by environments and habitual patterns of thought.

Recognise the sincerity of a persons intentions.

To think better in 3D.

2. Improvements in Dealing With People

I have tried to be more effective with people by employing the following simple rules:

a) Praise - credit when due.

b) Reprimand - used sparingly.

c) Interest - sustained and sincere.

I believe (a), (b) and (c) can be turned into management terms such as:

a) Targets

b) Knowledge of results

c) Knowledge of situation

I have also found it useful to keep in mind the following:

Self criticism

Respect other's self respect.

Remember differences between people (not like us, or like each other), different in background, experience, intelligence, education and characters.

Put oneself into other person's shoes.

Once aware of the problem of communication it is amazing how it breaks down at all levels. I have tried to improve this by:

Imagine instructions are to myself.

Give all facts, ensuring not just passing the 'buck.

i.e. some unwanted job.

Ensure person is fitted with necessary qualities.

Another important facet of communication is the control of meetings, that normally get out of hand. I try the following:

Establish what meeting is about and information required to be extracted.

In other words select plane.

Keep meeting on correct path.

Try and disengage from discussion and take stock.

3. Tools Provided by F.D.M. as a means to Improving and Making More Efficient One's Work.

I try the following in analysing other people's written or implied words.

Read the article or statement.

Underline the important words.

Interconnect the marked words find relation to each other.

Challenge each statement.

1. Ask what is being said.
2. Does he really mean this?
3. The true significance of what is said.
4. Read between the lines for hobby-horses, obsessional traits, etc.

Determine cause of cutout in one's understanding.

Penetrate further to discover basis of this deficiency (even if it is lack of knowledge in self, or lack of communication in other person.)

The following is a means I employ in analysing my own answers as solutions to problems.

Does a particular answer indicate a control on the way I am viewing a statement?

Can I see a way to change approach to increase the benefit gained from answer?

Is the answer unjustifiably influenced wrongly by fear, emotion, etc.?

Has the answer been formed from the statement 'It is obvious'?

Method used in my approach to a problem

1st stage - Diagnostic

What is going on here - what is happening - 80% time spent on this stage usually profitable - must be correct.

2nd stage - Judicious

What do I want to bring about by any action taken?

If this is going on and I want to do something else, what is stopping me, how much freedom?

3rd stage - Creative

Find at least two lines of action. Which is better one?

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2 OF 2

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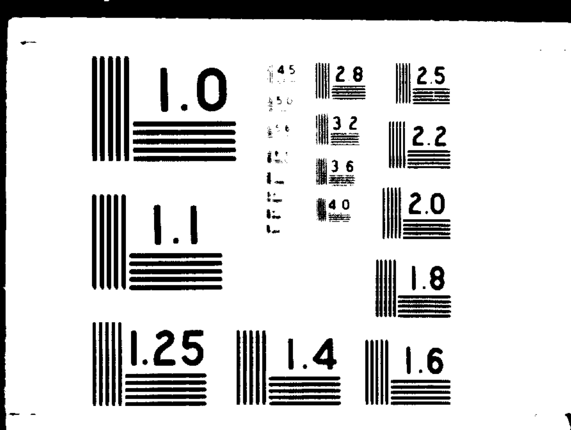


4th stage - Administration

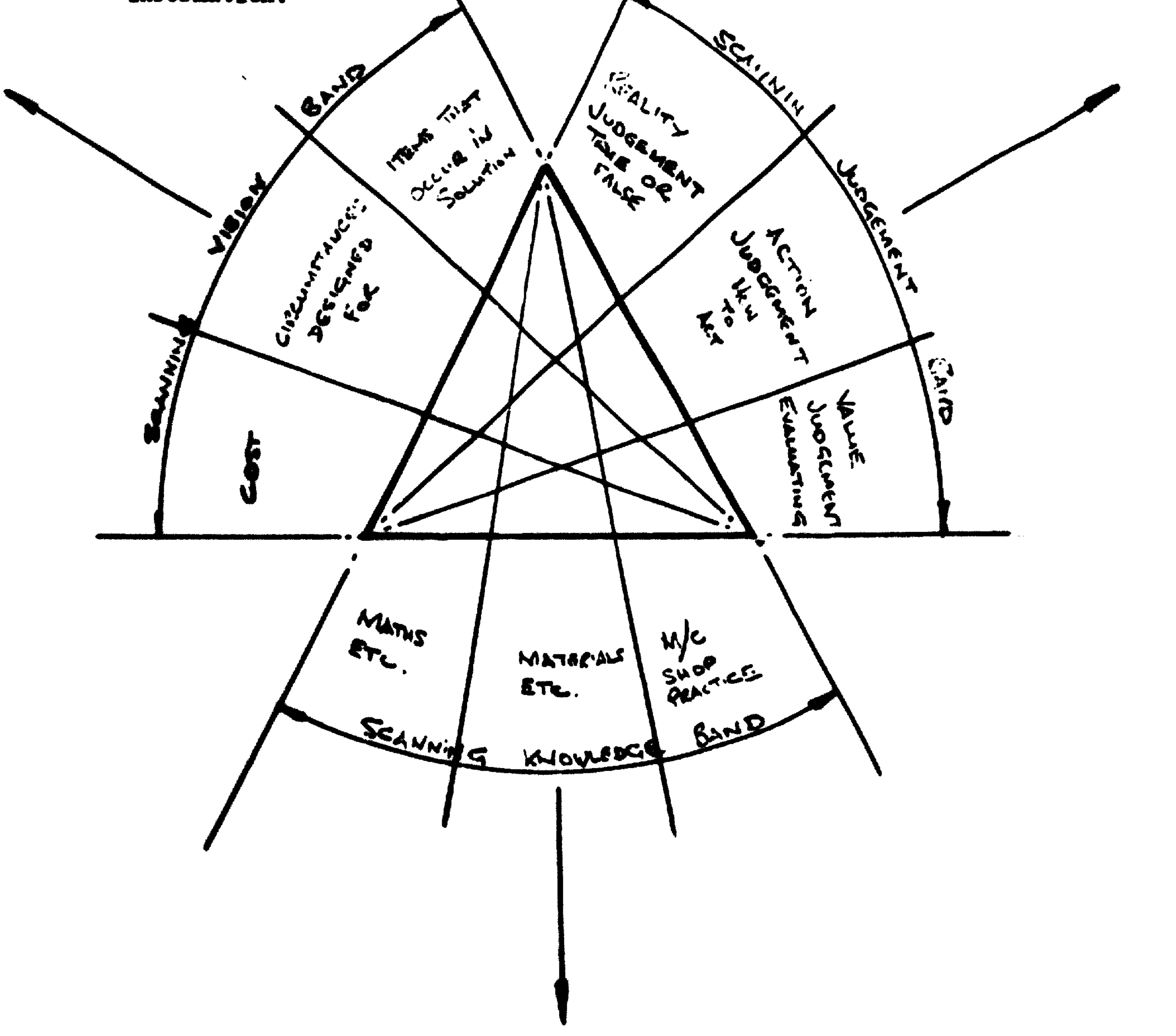
Action or implementation.

Methods used in obtaining a greater degree of control over the design process

I have chosen aids which I have used because of the set of circumstances encountered since course. There are many other aids I could use if circumstances had been different, i.e. position of project in time, type of project, etc.

Start with making exhaustive random list of all possible significant factors, from specifications, terms of reference, past experience, past designs, other designs, manufacture, testing, etc.

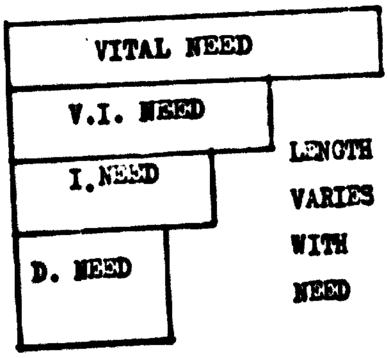
By using the knowledge, vision, judgement triangle this helps to extract further information.



Each side is split into as many units known and scanned over scanning band, one can go deeper at any point by progression.

Having collected this information one ne ds to relate the relevant statements into collective headings.

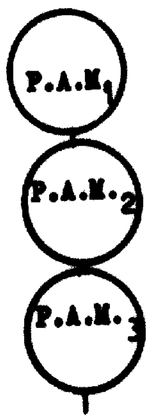
By making a graph of these headings into groups of Vital Need, Very Important Need, Important Need, Desirable Need.



From this it becomes clear what is the Primary Functional Need.
(the need which, if not satisfied, invalidates all other achievements).

A further help to clear the mind from wrong controls is to reduce all needs to the basic 'Provide A Means'. This is simply to take each need as follows:

Need = Keeping Essential Nature of need and produce as many numbers of alternatives as possible =

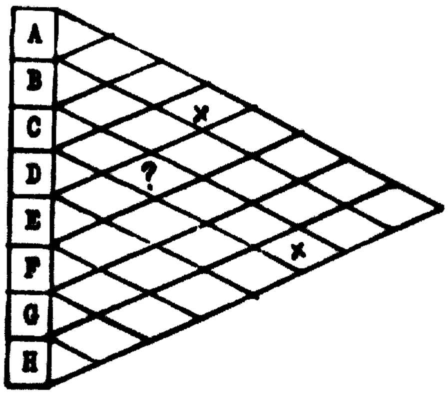


etc.

Also employed at this stage to ensure that nothing but true requirements remain is firstly the <u>Primary Roulette</u>

How can we Eliminate
Combine
Standardise
Transfer
Modify
Simplify
the whole or part.

and secondly, The Secondary Roulette
the Effects/Demands/Restrictions, each will have on the other. By graphing and lettering items this can quickly be run through.



At all stages it is essential that one stops and takes stock and backtracks to ensure that the functional effectiveness is still being satisfied.

One needs to develop a number of alternative forms around the chosen concept.

A detailed study of material and work content involved in every life stage of product is necessary.

The above does help one realise more fully how one does the thinking work, and how essential that controls be applied when necessary to the mind.

APPENDIX NO. VI

MAKE AND BUILD PROJECT REPORT

PART OF REPORT BY N.A. STOKES

SEPTEMBER 1968 to JANUARY 1969

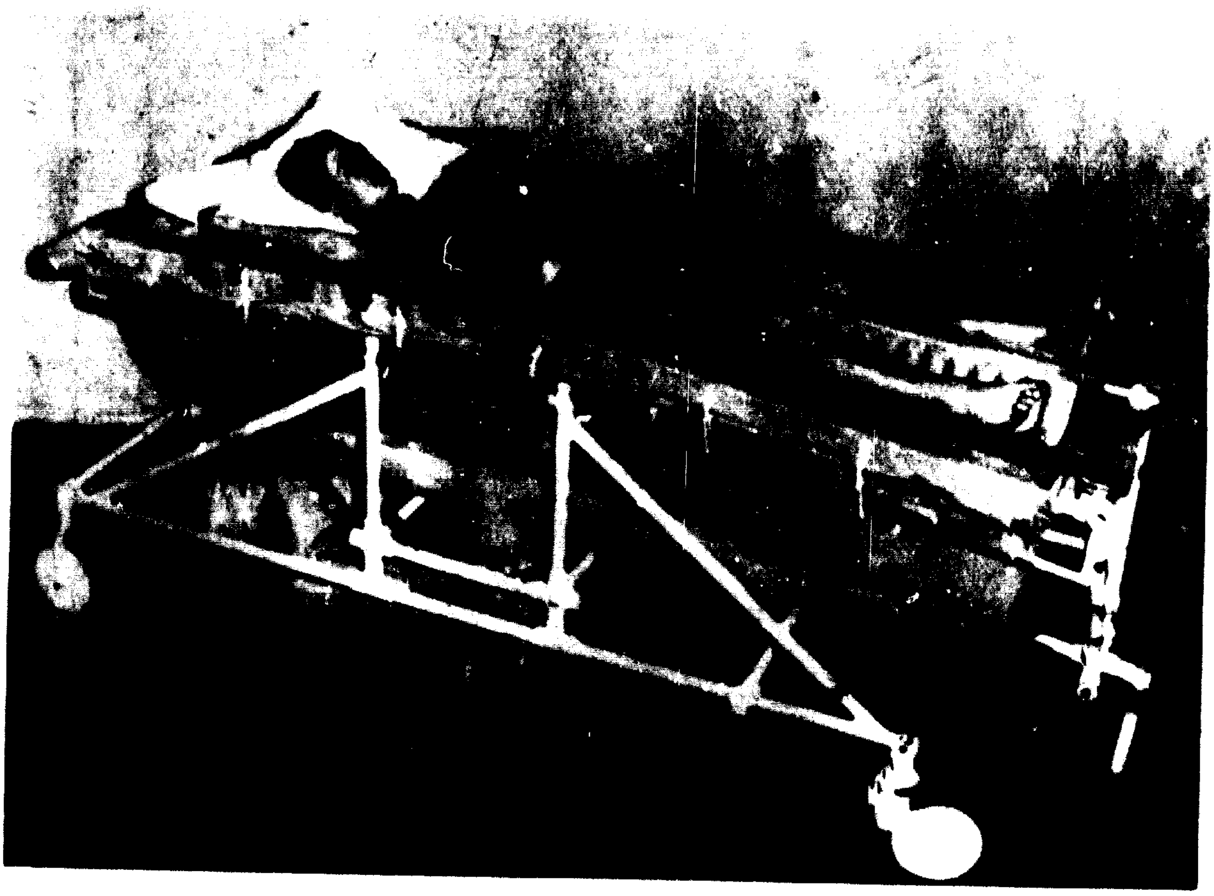
The greatest challenge of all, during the course, was the 'design-and-build' project. Not only did my group and myself have to build a machine, but we also had to work out a feasible design from the specification supplied by the sponsor. In my case, the task was to design and build a machine capable of polishing a small turbine rotor blades to a 32 micro-inch finish within a 0.005" tolerance on each surface. The problems were well appreciated in a project of this kind as no-one had yet accomplished such a task in industry, After much research and compilation of a feasibility study, (all very worthwhile experience), a design was finalised and accepted. Manufacture was then able to commence. Besides the experience gained in engineering drawing and all types of machining and fabrication entailed by the project, further managerial knowledge was achieved as all ordering, buying, costing, and reports had to be compiled by members of the group

APPENDIX NO. VII

EM&D DESIGN CLASS I AWARD

The Awards committee unanimously agreed that the Class I Award should be made to Mr. L.A. Hopkins for the design of the Hoverbed. (The design is shown below in the photograph.) An extensively burned patient suffers from shock which is soon made worse by massive fluid loss from the damaged skin. Immediate transfusion of blood and plasma is give to sustain the blood pressure and attention is given to the burned area.

The commonest cause of death in these patients is infection, against which several methods are in current use. Antibiotics may be given. The patient may be nursed in an isolator and the skin surface may be treated to cause coagulation of the tissue proteins, so making the surface less hospitable to bacteria. At the same time the patient must be supported comfortably, preferably with access to the burned area. The Hoverbed provides a novel solution to these problems and has stimulated world-wide medical interest. The patient is painlessly supported in a sterile environment in which temperature and humidity are easily controlled. The drying effect of the air current over the skin forms a coagulum which prevents fluid loss and within 24 hours becomes mechanically strong enough to permit the patient to be nursed in an ordinary bed with a much reduced risk of infection.



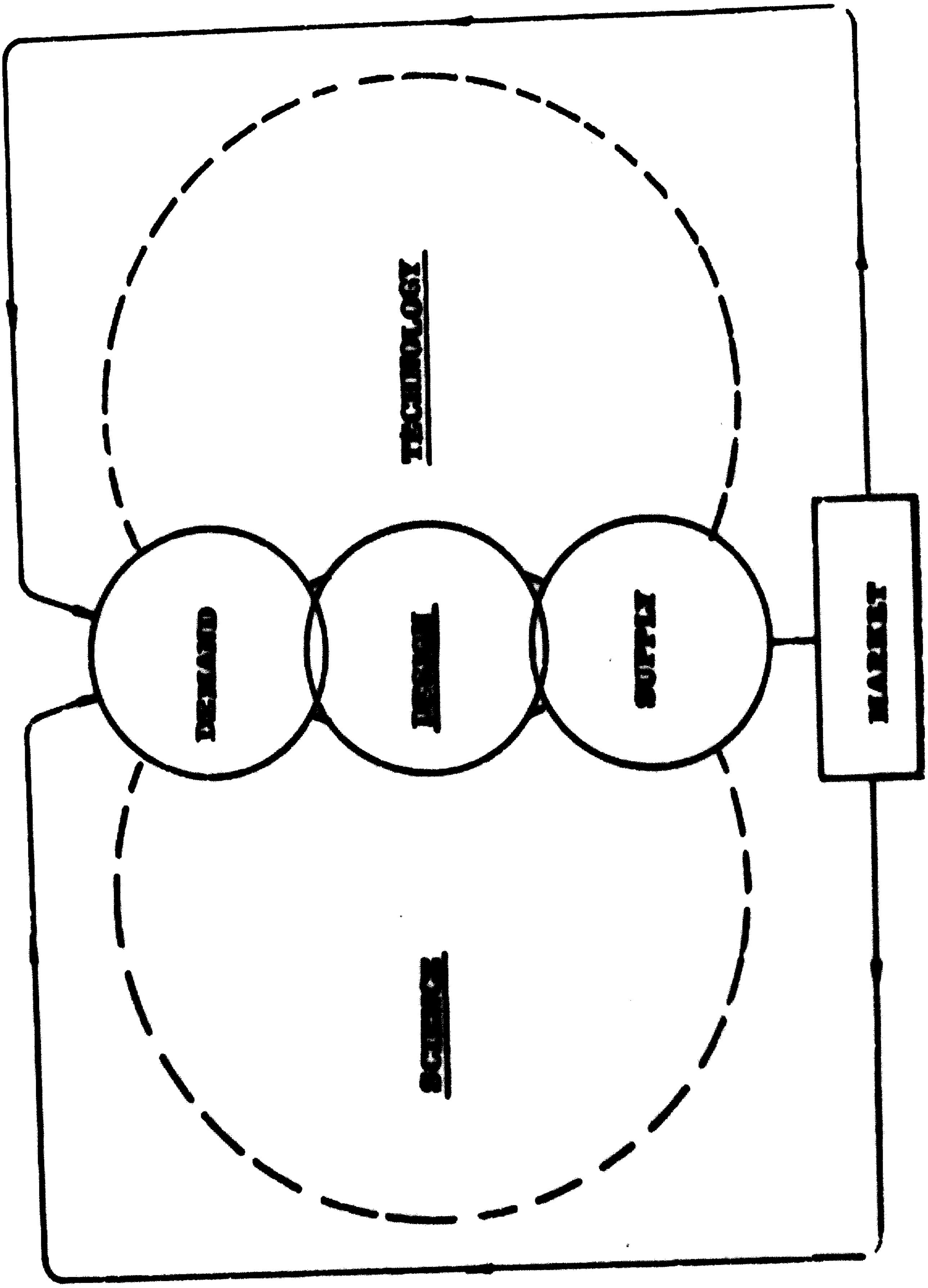
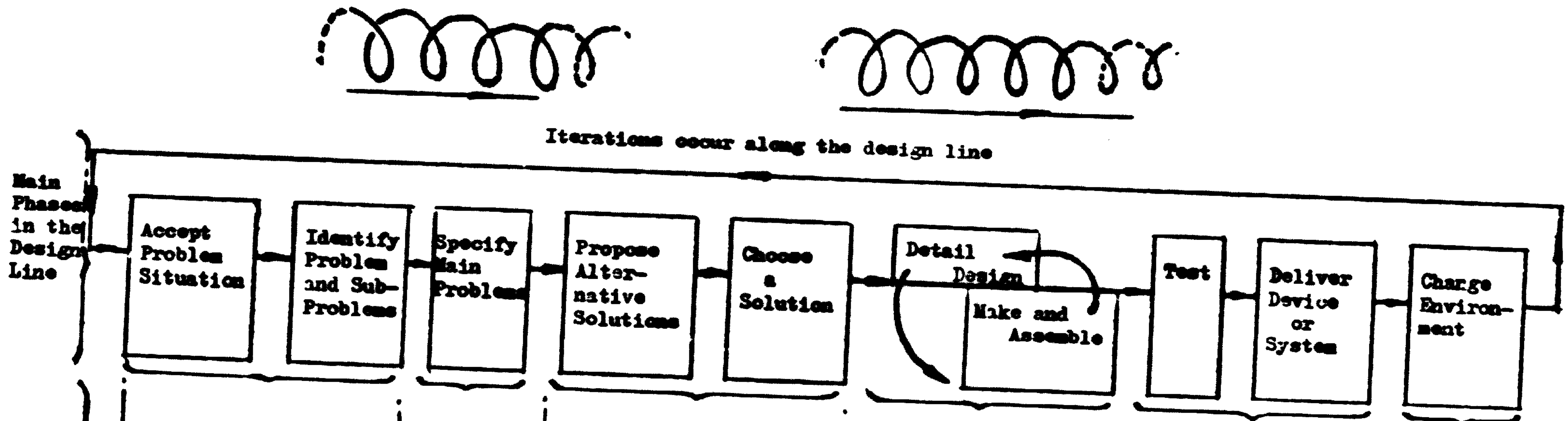


FIGURE No 1.



Intellectual Skills and Abilities						
Sensitivity to the existence of a need, and problems associated with that need.	Ability to accept ill defined problem and isolate it from irrelevant data and information and identify main facets. Ability to express these verbally.	Creative ability. Ability to manipulate analogues and models and to predict possible outcomes. Judgement.	Ability to create favourable forms, best containment configuration, etc. Spatial ability, size, shape and strength considerations. Ability to think in 3D to obtain geometric shapes and express these in 2D. Ability to make reconciliations & compromises, having regard to cost. Ability to communicate graphically and verbally.	Ability to analyse results and predict effects of feedback	Ability to perceive effect on total system.

Intellectual skills and abilities associated with the design line

FIGURE NO.2.

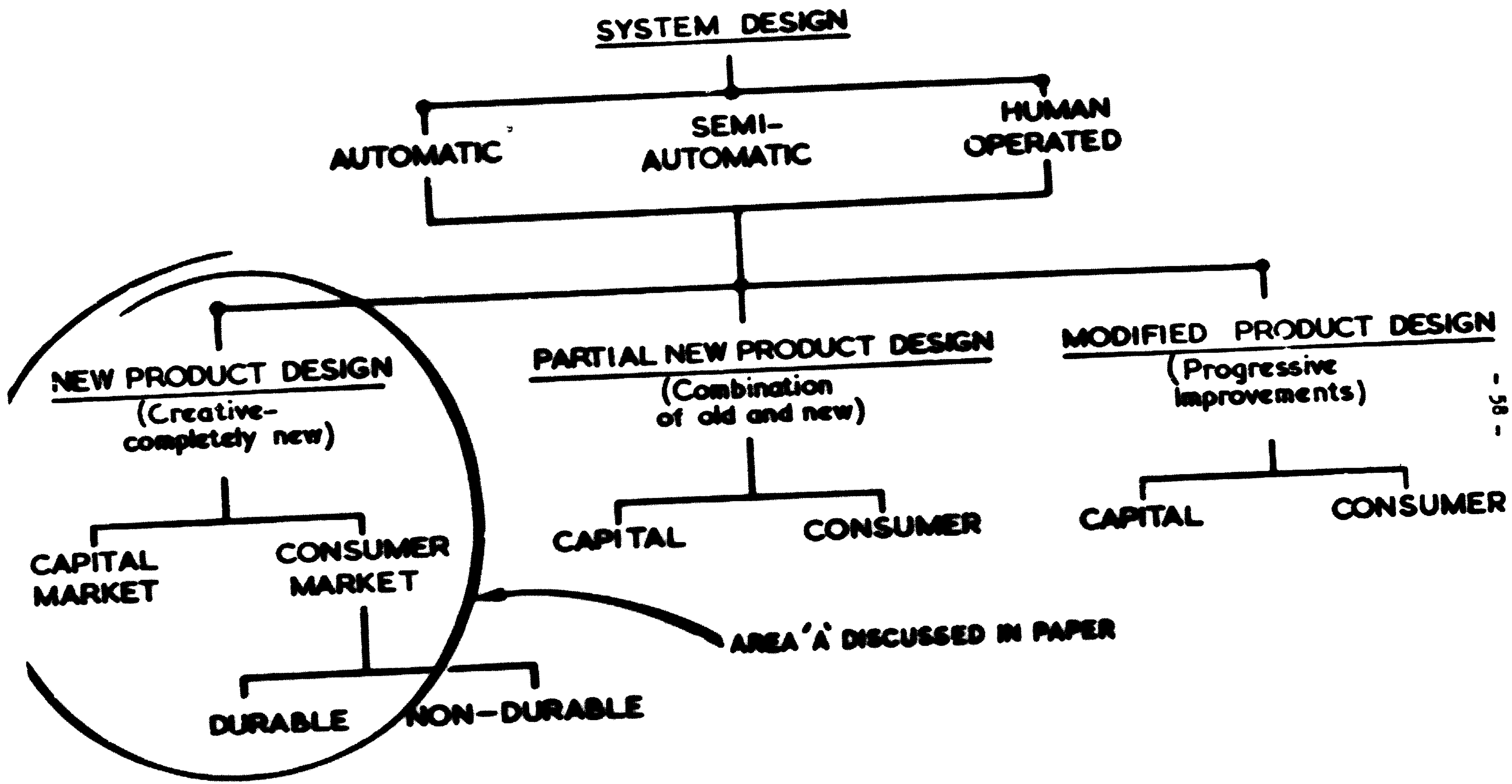


FIGURE No3 FIELD OF COVERAGE OF ENGINEERING DESIGN WORK

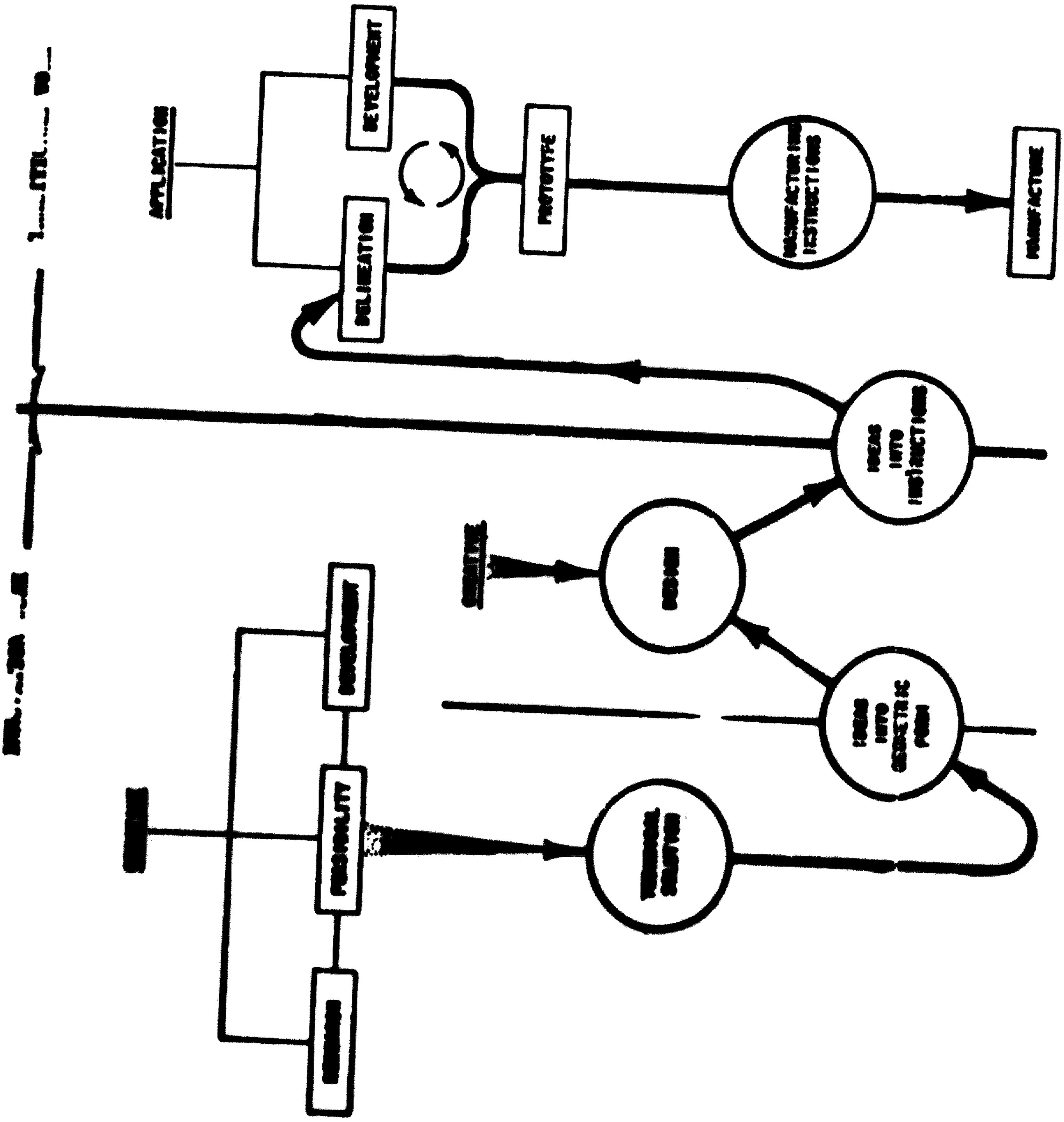

APPLICATION
DEVELOPMENT
DELINEATION
PROTOTYPE
MANUFACTURE
IDEAS INTO INSTRUCTIONS
FEASIBILITY

FIGURE No4

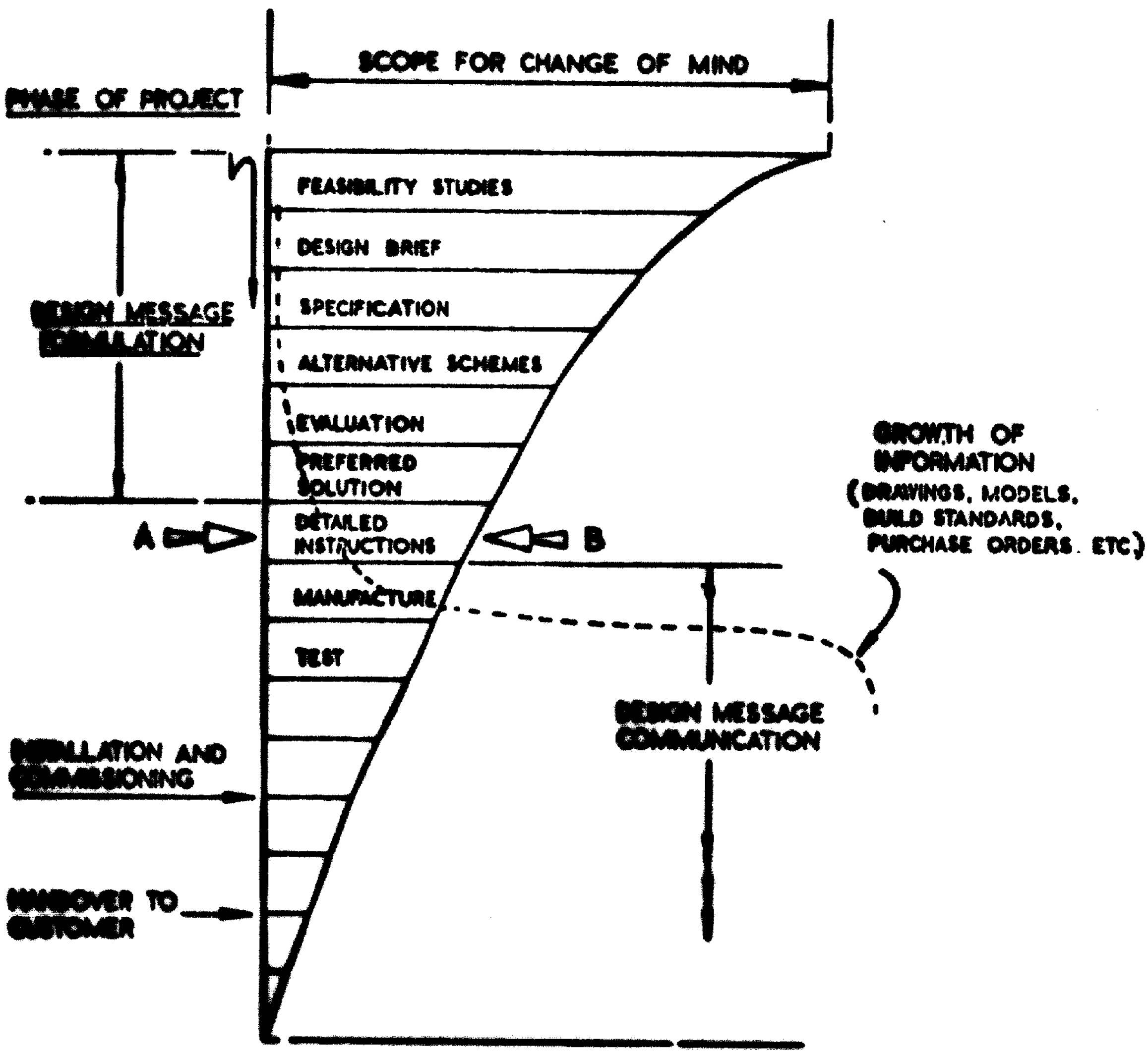

SCOPE FOR CHANGE OF MIND
PHASE OF PROJECT
FEASIBILITY STUDIES
DESIGN BRIEF
SPECIFICATION
ALTERNATIVE SCHEMES
EVALUATION
PREFERRED SOLUTION
DETAILED INSTRUCTIONS
MANUFACTURE
TEST
DESIGN MESSAGE FORMULATION
A
B
GROWTH OF INFORMATION
(DRAWINGS, MODELS, BUILD STANDARDS, PURCHASE ORDERS. ETC)
DESIGN MESSAGE COMMUNICATION
INSTALLATION AND COMMISSIONING
HANDOVER TO CUSTOMER

FIGURE 10.5

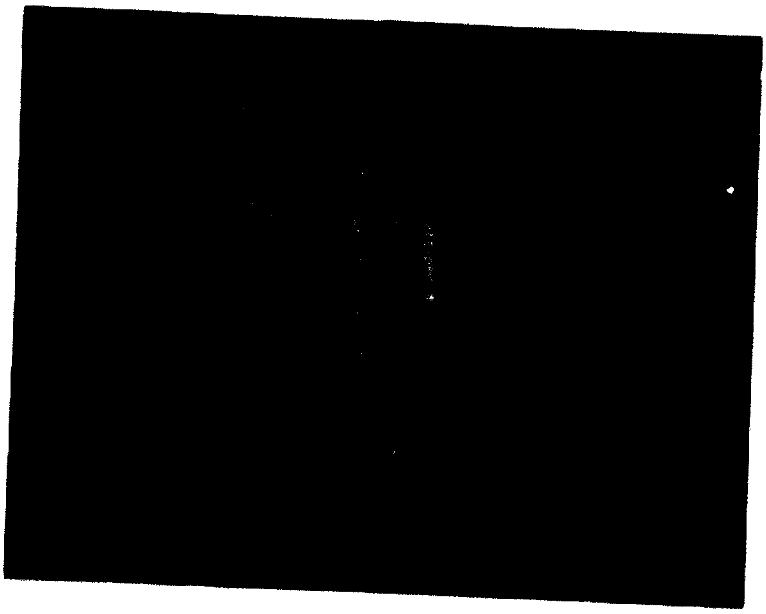
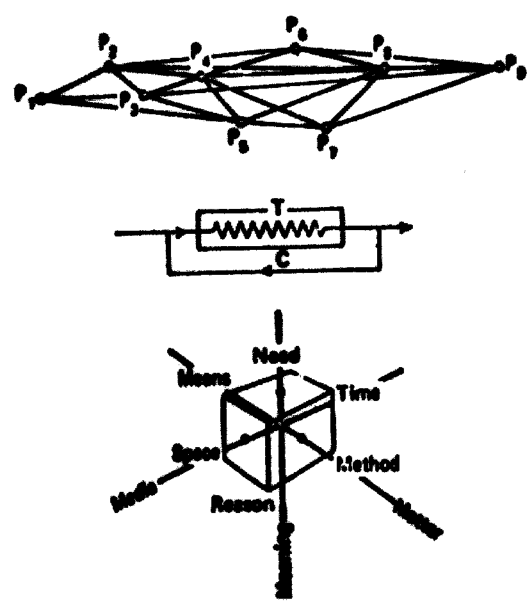


FIGURE No 6(a)

FIGURE No 6(b).



Fundamental Design Method

Figure No7

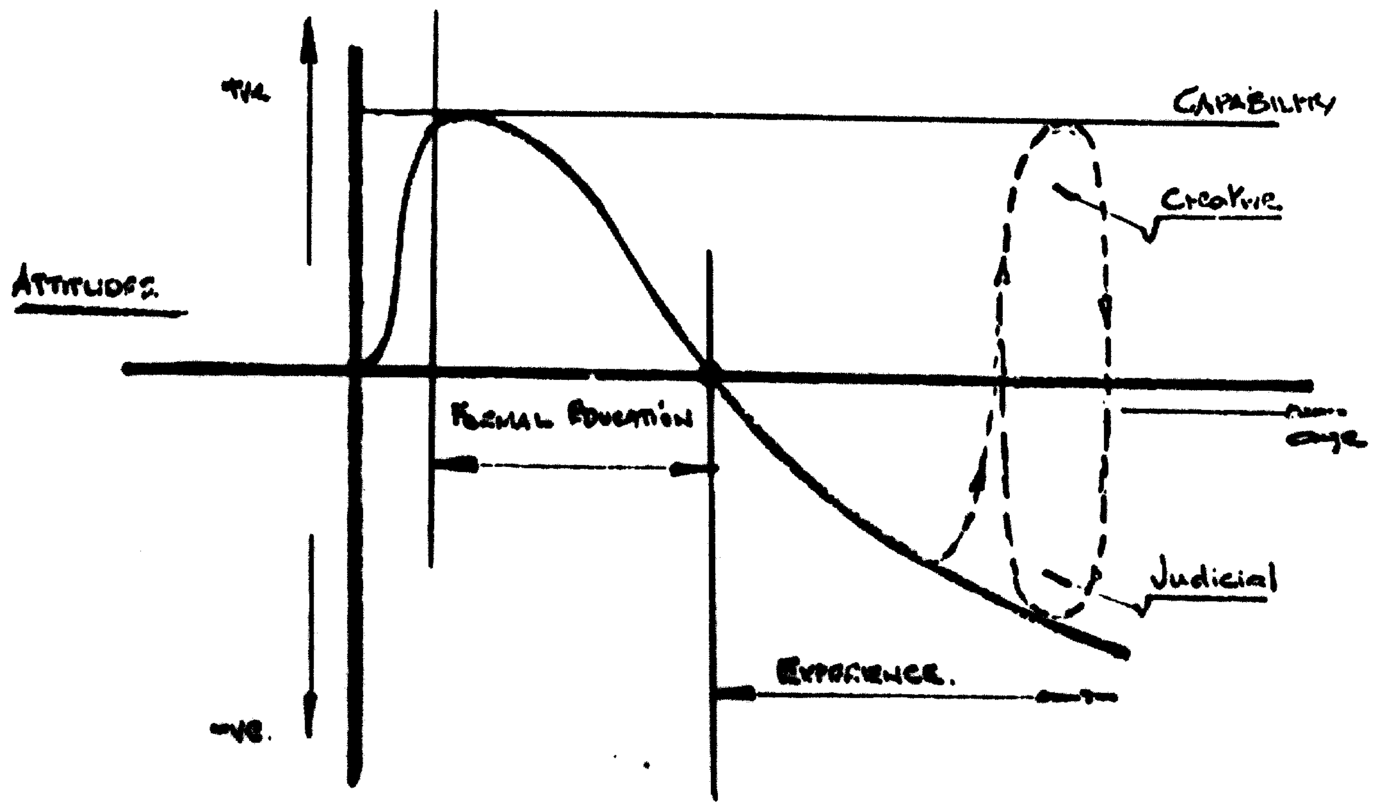

Capability
Creative
Attitudes
Formal Education
age.
Judicial
Experience.

Figure No 8.

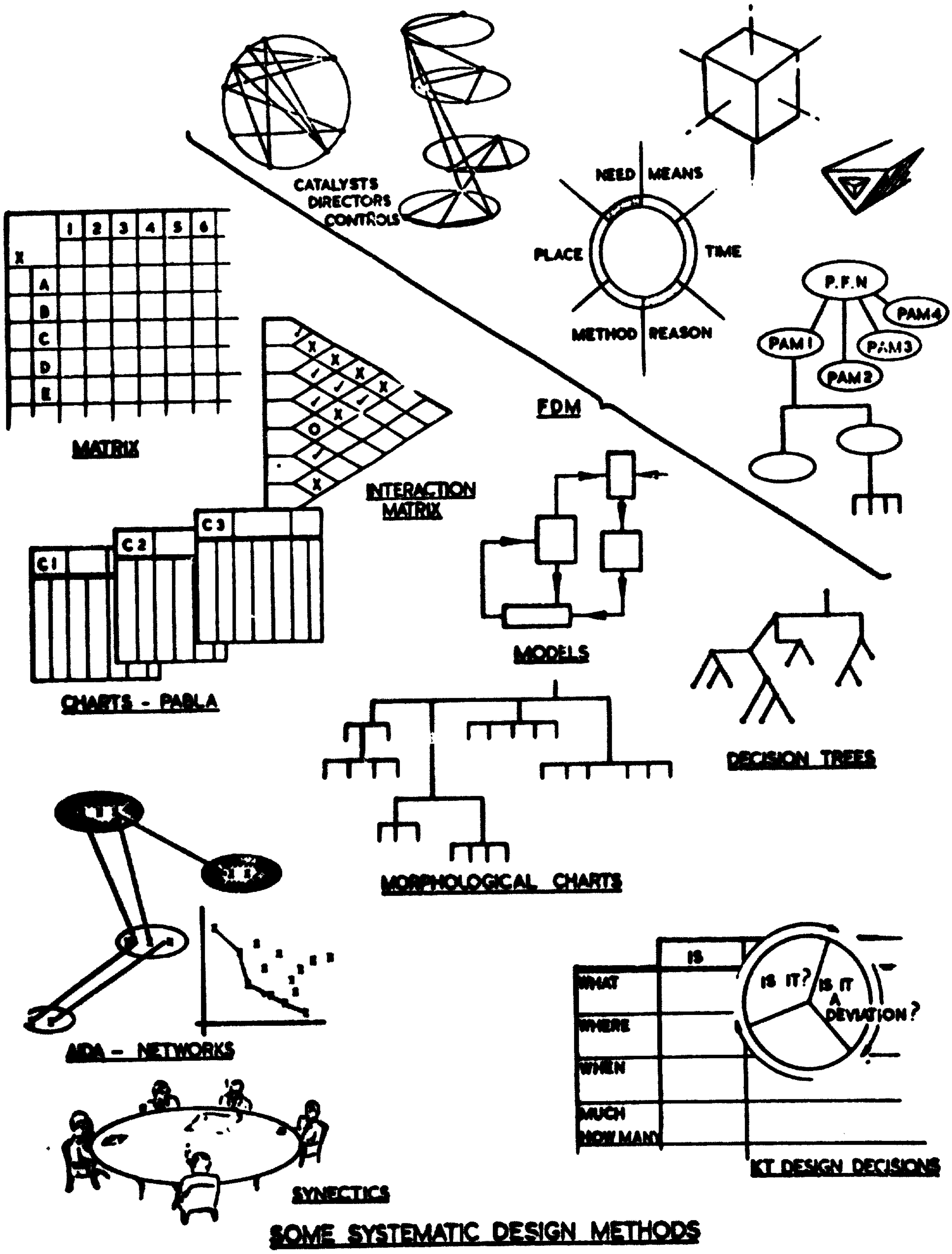
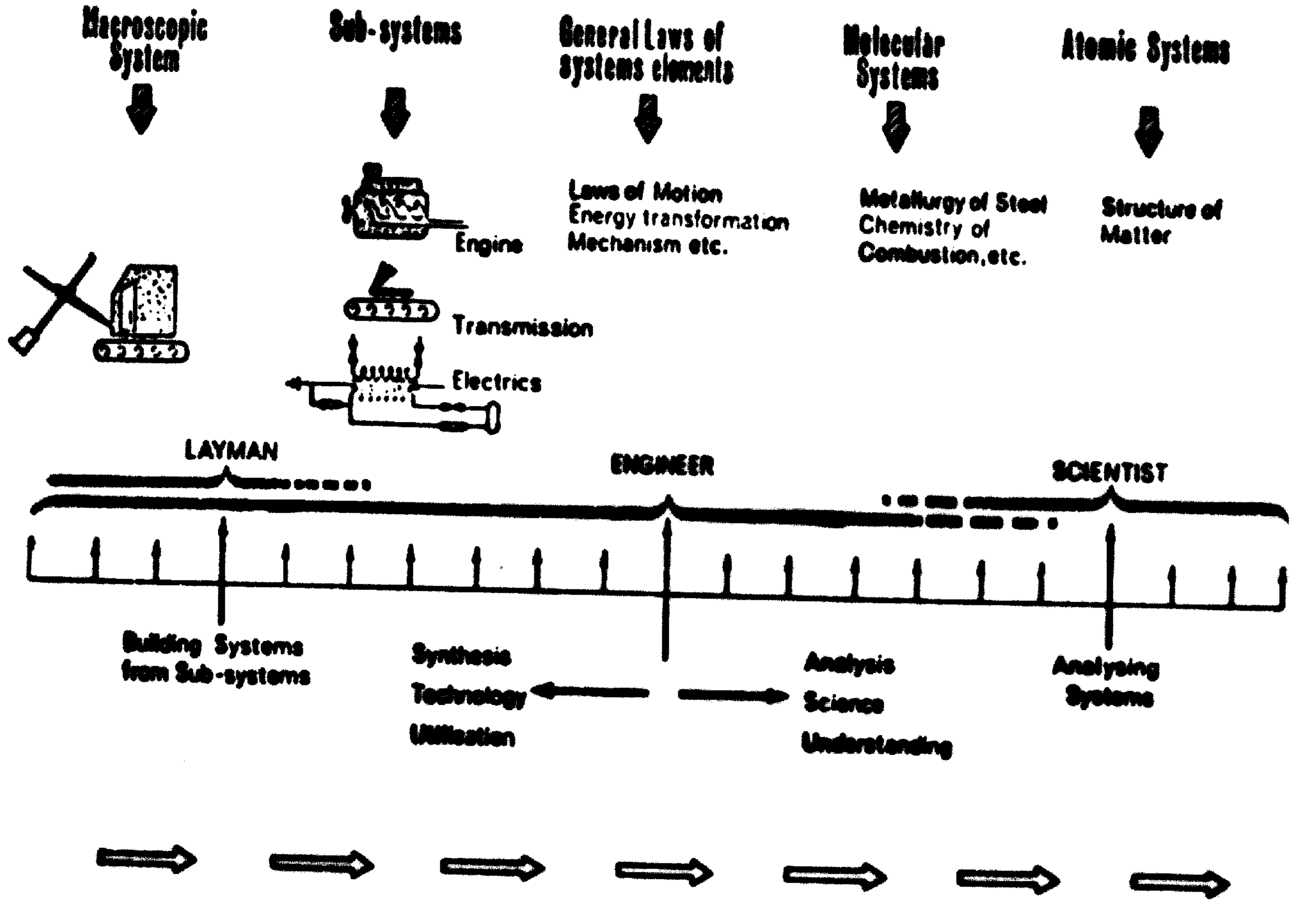


Figure 9 Present systematic design methods, in analogue form

FIGURE No 9



Progressively increasing need for improved methods of interrelating and handling ideas such as mathematics

Synoptic view of teaching requirement

FIGURE No 10

10. 8. 72