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THE ROLE OF COMPUTER-AIDED DESIGN IN THE LEARNING OF PRACTICAL 3D-DESCRIPTIVE GEOMETRY: A CASE STUDY

Geoffrey Alan Edwards BA (Hons) Fine Art, ATC.

submitted in partial fulfilment of
the requirements for the degree of
MASTER OF PHILOSOPHY

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ABSTRACT

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There are a number of problems surrounding the teaching of practical 3-D descriptive geometry to children in secondary education, notably the difficulty pupils have with visualising an object's form from orthographic views, and the interpretation of an object's geometric attributes into the descriptive geometry representation.

The purpose of the current research is to evaluate the use of computer-aided design in this area of the curriculum and is based upon work undertaken in a North London comprehensive school. The school and its context is described and evaluated.

Theories of child development and educational psychology of relevance to the study are reviewed, notably the work of Piaget, Bryant, Gagne, and Freeman.

The history and nature of 3-D descriptive geometry is reviewed in practice and in education, with special reference to various methods employed in instruction.

Dr. J. Vince's PICASO SYSTEM of computer subroutines and functions written in FORTRAN for graphic applications is explained as a means of teaching the subject, with special reference to the researcher's own instructional material and computer programs. The use and effectiveness of these teaching materials are related and evaluated in the light of students' performance and results.

The research concludes that the special benefits of computer graphics in this field are: the economic production of appropriate didactic material under the direct control of the teacher, increased pupil motivation due to the use of better illustration and the interest generated by computer-aided design project work, and an opportunity to employ analytic geometry to support learning. Its limitations include: the high cost of the computer and peripheral devices, and the lack of a facility for modelling objects by the removal of solid volumes in the existing software. Further research is recommended in the areas of computer graphics, descriptive geometry, and psychology.

AUTHOR DECLARATIONS

1. During the period of registered study in which this dissertation was prepared the author has not been registered for any other academic award or qualification.

2. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

3. The programme of advanced study of which this dissertation is part has consisted of:

   3.1 Research Design and Methods course.

   3.2 Participation in Research Colloquia.

   3.3 Supervision tutorials

   3.4 Attendance at relevant research conferences

GAEdwards

Geoffrey Alan Edwards

15th May 1988

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE PROBLEM

1.1.1 THE AIM OF THE INVESTIGATION

The aim of the investigation is to examine the benefits of computer-generated graphics in the learning of spatial concepts and descriptive geometry. The research is centred on a case study of work undertaken at Fortismere School, a comprehensive school situated in North London. An attempt is made to draw general conclusions based upon a comparison with other methods normally used in the teaching of spatial concepts.

1.1.2 THE SCHOOL SETTING

It is important to provide a brief account of the formation of Fortismere School because it helps one to understand the character of the school population and the sort of learning problems that the teacher has to contend with.

The London Borough of Haringey and its independent Education Service were formed in 1965 from the former Education Authority of Middlesex. Two years later the Borough's grammar and secondary modern schools were transformed into fourteen comprehensive schools. Tollington Grammar School and William Grimshaw Secondary Modern both in Muswell Hill formed CREIGHTON

SCHOOL. Bounds Green, Cecil Rhodes and part of Parkwood Girl's School in Wood Green jointly formed ALEXANDRA PARK SCHOOL.

The need to deal with a rapidly falling school population subsequently led the borough to propose and the Department of Education and Science (DES) to accept (January 1982) the reduction from fourteen to ten secondary schools in Haringey by means of four pairs of amalgamations, consequently Alexandra Park and Creighton closed in the Summer of 1983 to be replaced by the single Fortismere School.

The new school initially occupied three sites located on two campuses - Wood Green and Muswell Hill. The school population of 1,800 pupils spread over three sites gradually declined to 1,300 by 1986, in which year it was possible to locate the whole school on the Muswell Hill campus. The Muswell Hill campus consists of two sites called respectively the North Wing and South Wing of the school. The wings are about 500 metres apart. Many departments of the school are split between the two wings, this has meant that some resources are relatively inaccessible to certain departments.

Haringey is a multi-racial, multi-cultural society. There is a large immigrant community, composed mainly of West Indians, Greek Cypriots and Asians. At the time of the last official census it was found that Haringey has the largest proportion of immigrants in the whole of the UK. Fortismere School has a school policy of equal opportunities to ensure that no particular group of pupils is placed at a disadvantage in relation to any other group. Fortismere also has a commitment to mixed-ability teaching; there is no streaming or banding according to pupil's ability. Most teaching in the early years takes place in mixed-ability groups with increased amounts of setting as public examinations approach. The school opened with a staff of some 135 teachers appointed predominently from the two contributory schools.

1.1.3 TIME FACTORS

Practical three-dimensional geometry is a major component of the examination subject Technical Drawing. Technical Drawing (TD) has been largely superseded by the new subject Graphical Communication. In keeping with other schools in the UK Graphical Communication is offered in the fourth year as a two-year examination course leading to either the Certificate of Secondary Education or the General Certificate of Education. The length of time devoted to Technical Drawing or Graphical Communication in years 1-3 varies widely in the UK, from none at all to courses of a term or a year (HMI Discussion Paper: TD Courses In Secondary Schools 1984). At Fortismere School and one of its predecessors - Creighton School - the time allocated to the subject has varied over the decade 1976-86.

As the researcher was formerly a teacher at Creighton School and had been teaching Technical Drawing and latterly Graphical Communication since October 1976, the variation in time allocated to the subject has been a major factor, and will be discussed later in the rationale for the research.

Prior to 1976 when the investigator came to Creighton School and up until 1980, when the Head of Technical Studies retired, Technical Drawing was taught from the first year to all pupils. The other technical subjects included Woodwork, Metalwork, Home Economics, and Textiles. Two lessons out of the forty period week were allocated to Technical Studies. The five subjects were taught in rotation. Instead of dividing the number of lessons in the school year by five to allocate an equal amount of time to each subject it was considered to be more appropriate to provide the children with a change of studies at the beginning of each term. Unfortunately this decision leads to the children having an extra term of one of the subjects. The situation was further complicated by the necessity to divide each tutor group into smaller groups so that they could be accommodated in the workshops. Due to shortage of space the Technical Studies department was split between the two wings of the school consequently there had to be a certain amount of duplication of resources and also movement of equipment, staff and pupils between the wings; time had to be allocated for this movement, resulting in a reduction in lesson time.

The new Head of Department appointed in 1980 decided in consultation with his staff to phase-out the traditional subjects: Woodwork, Metalwork and Technical Drawing. In place of the discontinued subjects the first and second years would be taught Craft, Design and Technology (CDT); the design component of CDT requires TD skills so a certain amount of TD would be taught within CDT. Technical Drawing would continue in the third year and would be replaced by the new syllabus - Graphical Communication. The reduction of the five subjects to three meant that it was possible to arrange for first and second years to have one lesson a week throughout the year of CDT; the other lesson was split between home-economics and textiles, being allocated a half year each.

1.1.4 LEARNING MATERIAL SUITABLE FOR YEARS 1-3

An important consideration in curricular development is the availability of suitable teaching materials and an invaluable source with regard to the use of classroom material is the National Reference Library of Schoolbooks and Classroom Materials. Housed at the library are all books and other materials intended for use in the classroom that are currently available for purchase from British publishers. Use was made of this library to inspect textbooks and other material designed to be used for teaching Graphical Communication and Technical Drawing.

There is very little available material suitable for teaching third years and none that this writer can describe as being suitable for use in a mixed-ability classroom from the first year. This observation is based on visits to the library in 1982 and more recently (April 1988). Visits were also made to Foyles bookshop which also holds textbooks from the USA and other English speaking countries.

The paucity of instructional material for the younger pupil is probably due to the variation in time devoted to technical drawing courses in years 1-3 at British Schools (see 1.1.3 above) as textbook writers do not have a great incentive to write for an ill-defined area of the school curriculum. Consequently teachers have either to adapt existing material that has been designed for examination courses or develop their own material.

The investigator tried modifying examination course material but for reasons that will be more apparent later he eventually decided that it would be better to develop new instructional material for his younger pupils.

1.1.5 TECHNICAL DRAWING AND GRAPHICAL COMMUNICATION

The practice of technical drawing is popularly associated with the making of plans for machines, buildings, or similar artefacts. But technical drawing expertise is also required for all kinds of technical and scientific illustration, graphic design, and for the construction of graphs, charts, maps, diagrams and electrical circuit drawings (GIESECKE, MITCHELL and SPENCER, 1949).

Technical Drawing as a school subject primarily involves drawing for Woodwork, Metalwork, and Design and Technology. The subject requires an understanding of practical plane and solid geometry. This geometric knowledge forms the basis for applying the method known as orthographic projection to depicting the form of any object (ABBOTT,1962). Descriptive geometry provides an understanding of the underlying theory of orthographic projection so that various problems involving spatial relationships may be solved (SLABY,1976). A comprehensive account of the mathematical and technical components of the science of representing spatial objects and structures graphically is given in Chapter 3.

Graphical Communication was introduced to replace Technical Drawing courses which excluded various areas of application listed above, and which had been regarded as too craft based. To encourage teachers to introduce design into their courses the examination includes questions in which the pupil is required to provide a design solution. All areas of application listed above are now incorporated into the syllabus.

1.1.6 A COMMENTARY ON TEACHING TECHNICAL DRAWING

SMITH (1965) mentions that there had been a neglect of the study of technical drawing in the UK (SMITH, 1965, p304). A similar situation prevails today (see section 3.1 below). The following commentary, which is based on personal experience, contains some views into the teaching of technical drawing that the reader is unlikely to find elsewhere. The commentary is also essential to an understanding of why this research was undertaken.

On appointment to the school careful note was taken by the writer of the teaching procedures of his colleagues in the department. There was one teacher who primarily taught technical drawing and who had responsibility for the subject as well as careers education. All teachers in the department taught TD as well as teaching varying amounts of woodwork and metalwork. Books were available to teach geometrical drawing (HALLIWELL & WATERHOUSE, 1968; HEARD, 1969; MAYOCK, 1969) but teachers usually preferred to teach the subject from the blackboard.

The lesson time was generally used to introduce a topic or a few very closely related topics to the class which consisted of boys and girls of mixed-ability. Occasionally two lessons were used particularly for engineering drawing which takes more time. Books were available for engineering drawing (MAYOCK, VOL 5, 1969; STEPHENS, 1969). The latter consisted of exercises. The teacher would initially help the pupils to understand the question, this was accomplished by class discussion and a partial construction of the solution on the blackboard. Some teachers employed worksheets that helped the pupil to understand the work; nevertheless, the teacher went carefully over the topic on the blackboard. Since the whole group of pupils were taught the same topic at the same time, and these pupils varied in ability, the teacher had to be especially careful to suit the topic to the average ability of the group, whatever their age.

Initially, whatever the age of the pupil, an agreed objective was to provide an opportunity for pupils to gain some degree of skill in using the tee square, set squares and compasses. This was usually achieved for most pupils by the construction of simple patterns, which could be coloured or shaded in some imaginative way (For typical examples see HOLBROW 1944).

Before the concept of orthographic projection can be introduced it is necessary to familiarise the pupil with the idea of a single view (orthographic view) of various objects. These single view drawings need to be constructed to scale, usually full size, to conserve the technical nature of the work. This is more difficult than it seems, consequently the subject matter needs to be fairly simple. The rate at which new concepts can be introduced tends to be quite slow otherwise the pupils either fail to finish the topic or produce unsatisfactory work. The problem is aggravated by the difficulty some pupils have with the instruments. They tend to become pre-occupied with technical problems rather than with the concepts which the teacher wishes them to grasp. The teacher can either press on, introducing new concepts at a reasonable rate, or slow the pace and give more time to the slower pupils to acquire the requisite drafting skills. Additional work can be given to the more able to keep them usefully occupied.

There are some pupils who never gain a reasonable facility with the equipment, even after completing an examination course in the fifth year. The progress that these pupils make tends to deteriorate as they become older, and this deterioration is probably due to a sense of failure caused by getting further and further behind the rest of the group.

Another disadvantage of trying to teach the same topic simultaneously to a mixed-ability group, is that occasionally the more able pupil fails to finish work to a satisfactory standard, due to a lack of interest in the topic which he or she regards as being too easy to bother with. The teacher has also to contend with a situation where it is expected that all pupils will be sitting the exam at the same time. This is an unfortunate situation, since every teacher knows that some pupils - through no fault of their own - are not yet ready to sit the examination.

Another problem associated with teaching the same topic to the whole group is that of attendance: crucial lessons may be missed due to illness or some other cause. Attempts to provide a remedy for pupils who miss lessons are rarely satisfactory: schools do not have the resources of the Open University; the teacher is unlikely to be able to provide an informative video of the lesson. Consequently teachers tend regularly to review certain aspects of the subject often at the expense of further progress. Often a school is unable to provide books for each pupil who studies Technical Drawing except for classroom use. Consequently it is difficult to set suitable homework; moreover suitable books often go out of print.

Many of the problems of teaching technical graphics involve either problems that result from a lack of understanding of three-dimensional spatial relationships or drafting: either perception of actual three-dimensional relationships, or their representation on the two-dimensional space of the paper. Many pupils have difficulty with visualising and solving problems involving three-dimensional spatial relationships. These problems are discussed in Chapter 4.

Bearing in mind the difficulties mentioned above, the content of much of the type of work that is possible with instrumental drawing particularly with younger pupils, tends to be unsatisfactory in relation to understanding three-dimensional spatial relationships. Teachers are as a consequence quite likely to defer certain topics until either the fourth or fifth year. This may or may not be satisfactory, but many pupils who do not opt for the subject in the fourth year lose an opportunity to grapple with three-dimensional relationships.

The deficiency is unlikely to be remedied in their mathematical studies, as at present mathematics syllabuses do not include a descriptive geometry component: and even if they did, there is some evidence (reviewed in Chapter 2) to believe that the subject would be too hard to learn without an opportunity to apply it to creative design or to representing man-made objects.

1.1.7 THE INVESTIGATOR'S INSTRUCTIONAL MATERIAL

During the period 1976-80 the author spent a considerable amount of time developing material for an introductory course in technical drawing which could be used from the first year, if necessary, with mixed-ability pupils. The course material was designed and developed to enable a pupil to learn about representing three-dimensional objects graphically.

Bearing in mind a primary aim in a democratic society that all children should have an equal opportunity to be educated according to their capability to learn, it is the researcher's belief that the pupil's progress should not be hindered by schemes of work and school organisation that are not - on analysis - in the individual pupil's best interests. The researcher's objectives for the design of his instructional material included the following features that he believed to be essential: it should be possible for a pupil to make progress independently of the group; the material should attempt to stimulate the individual pupil's interest in the subject; and finally there should be no limit to what an individual pupil could learn.

It is unreasonable to expect the younger pupil to be able to read a lengthy piece of text in order to understand some concept or complete some task. Consequently if the physical form of the course material is primarily illustration and a little text printed on paper which the pupil has to interpret, it is essential that the illustrations should be particularly effective, as the pupil has to be able to visualise a three-dimensional object from them.

Although the researcher (a fine art graduate) was able to prepare illustrations to suit any application, the amount of work that would have been involved precluded what he considered to be essential to the development of an effective collection of instructional material, namely the facility readily to change the illustration. Ideally a designer of instructional material should be able to modify his or her material fairly easily after classroom trials. This is quite easy to do when the material is primarily textual but obviously difficult when there are a number of illustrations, especially when the illustrations have to be technical in nature. It was mainly to minimise these difficulties that the researcher considered using a computer.

It should also be noted that many technical studies teachers whilst being competent to teach drawing do not necessarily have sufficient skill to prepare good illustration.

1.1.8 COMPUTER PROGRAMS FOR TECHNICAL ILLUSTRATION

An extensive search was made (see Chapter 6) to find reference to a suitable program that could be used by a teacher or designer of instructional material to produce technical illustrations. No suitable program could be found. There were various languages that could be used to write programs for producing three-dimensional illustrations.
These languages enable a skilled programmer to make more effective use of a high-level language like FORTRAN. The researcher, who has some expertise in FORTRAN and also PICASO (a language written in FORTRAN), decided that it would be necessary to design and write a suitable program or programs.

1.2 STATEMENT OF THE PROBLEM

The objectives of the study in general terms were to:

1.2.1

write a critical evaluation of research in the areas of child development and theory of education in relation to the teaching of graphical communication and descriptive geometry;

1.2.2

design and write computer programs to facilitate the preparation of suitable illustration for the teaching of the practical three-dimensional component of graphical communication and related subjects;

1.2.3

design and produce, using a computer where appropriate, instructional material and teaching aids for use in the classroom;

1.2.4

undertake a case study and write a report of the possible benefits of using computer-generated graphics in graphical communication and related subjects;

1.2.5

produce recommendations for further research.

1.3 THE SIGNIFICANCE OF THE PROBLEM

1.3.1 THE IMPORTANCE OF PRACTICAL 3D DESCRIPTIVE GEOMETRY

The vast majority of manufactured objects and artifacts require the preparation of drawings in order to communicate the design of the object to those people who will arrange for its concrete realisation. The drawings which are usually referred to as 'plans', can function effectively as a medium of communication because of the incorporation of numerical and written information, which has been conventionally abbreviated according to national or international standards, and because the drawings have been constructed according to the science of descriptive geometry.

> "Descriptive geometry teaches us (1) how to represent objects and spatial forms as well as how to imagine and visualise them in space, (2) how to use construction methods for the solution of space problems, and finally (3) descriptive geometry develops a living, rich and at the same time real perspective ability to visualise, which is so badly needed in all technical professions, as well as in all kinds of scientific research work." (I.PAL 1966)

In school, pupils benefit by having an understanding of practical descriptive geometry as it enables them to engage in creative studies, and to derive greater understanding of illustrations from their school textbooks and from drawings which their teachers use. Typically, pupils learn descriptive geometry from courses in Technical Drawing or Graphical Communication. However, as noted in 1.1.3 TIME FACTORS, the amount of time devoted to the subject varies. Due to option schemes, some pupils may not have had any experience of the subject at all. There is also some evidence that many pupils learn rather slowly through courses of practical drawing, and that this might be because they are not given an opportunity to communicate their own ideas in the time available (H.M.I Discussion paper: TD Courses in Secondary Schools 1984). The writer has developed projects that give the pupil an opportunity to design an interesting object, eg., a spacecraft or car, but unless the project parameters are very carefully worked out an unacceptable amount of time may be spent on checking and correcting work.

It is theoretically possible for a computer to verify a design. With such a facility a teacher could offer pupils projects which involve them in the creation of individual designs knowing that some of the burden of checking, if not correction, will be done by the computer.

1.3.2 THE COMPUTER AS AN EDUCATIONAL RESOURCE

It is possible to spend a considerable sum of money on a computer, but if suitable software is not available the money would be better spent on some other resource. At present (March 1988) there is hardly any commercially produced software that could be described as suitable for the teaching and learning of three-dimensional descriptive geometry.

The development of computer graphics software and CAD software has tended to meet the needs of the drawing office by providing automated drafting facilities and sophisticated solid geometric modellers. There are many specialised graphics workstations designed to increase the productivity of the drawing office, these workstations are meant to be used by designers and drafting personnel who have been specially trained in their use. The concepts that need to be understood to make use of such workstations presuppose a level of maturation and cognitive development that school children do not have, which is of course only to be expected, since the workstations have been designed and developed for skilled educated adults.

Even the most enterprising companies are at present reluctant to invest in developing software for educational use, since apart from examination revision aids the market for other products is in its infancy. The author hopes that this study will stimulate interest and support for the development of educational software, and in a reappraisal of the role of descriptive geometry as a curriculum subject in secondary education.

1.4 LIMITATIONS

This study acknowledges the following limitations:

1. The period during which the study (including preliminary work) took place was Autumn 1981 to Spring 1986.

2. The enquiry was limited to the investigator's own pupils, who were aged 11 to 17.

3. The development of computer programs was restricted to three-dimensional descriptive geometry applications.

4. The computer programs were written in FORTRAN IV utilising the PICASO language.

5. The programs were run on the PRIME 550 minicomputer at Middlesex Polytechnic Computer Centre. With very few exceptions it was not feasible to take pupils to the computer centre.

1.5 DEFINITIONS

For the purposes of this investigation it is desirable to provide definitions of certain key terms.

1.5.1 DESCRIPTIVE GEOMETRY

> Descriptive geometry is the study of the spatial relationships of points, lines and planes and other surfaces. It forms the theoretical basis for all architectural and engineering drawing, because it provides the means for solving graphically the problems involved in the representation of three-dimensional objects by two-dimensional drawings. The method employed is called orthographic projection, and its working concepts are based on the theorems and axioms of plane and solid geometry. (Hoelscher, Encyclopedia Brittanica 1965)

1.5.2 ENGINEERING DRAWING

> Engineering drawing is the means of communicating the ideas of the engineer, designer or architect to the workmen who must produce a machine part, for example, or to a builder who erects a structure. With the increasing complexity of modern mechanical equipment and structures, it is necessary that the engineer, architect and draughtsman have a thorough understanding of the geometric principles of orthograhic projection upon which engineering drawing is based. The teaching of technical drawing in schools and colleges has tended strongly, therefore to rigorous instruction in projection theory. (ibid)

1.5.3 PRACTICAL DESCRIPTIVE GEOMETRY

For the purposes of this study practical descriptive geometry is defined as the study of three-dimensional descriptive geometry in conjunction with its application to engineering and constructional drawing and design.

1.5.4 TECHNICAL GRAPHICS

The term 'technical graphics' is used in this study to refer to any courses which include practical descriptive geometry as a component part: eg Technical Drawing, Technical Illustration, Graphical Communication, CDT etc.

CHAPTER 2

CHILD DEVELOPMENT AND EDUCATIONAL THEORY

2.1 DISCUSSION OF SOURCES

2.1.1 COMPUTER SEARCHES

Middlesex Polytechnic's Bounds Green Site library was the base for the literature search. An initial search was made in June 1981 using the Lockheed DIALOG computer data bases in the United States of America. Regular searches were made throughout the research period, either to explore certain areas or to update existing references. The BRITISH LIBRARY (BL) was requested to supply literature where no convenient local source could be found. A manual search of the BL's collection of: The Journal of Engineering Drawing and its replacement The Journal of Engineering Graphics, an American publication could not be undertaken as the BL had moved their holding to Boston Spa in Yorkshire. This is a pity as Boston Spa is rather remote, being situated on the moors midway between York and Leeds.

It is recommended that the BL do not remove journals to remote locations, especially when no other institution has a duplicate collection, and no index exists, and they are not prepared to make one.

2.1.2 OTHER LIBRARIES USED

In addition to the various Polytechnic Libraries the local library system was also used. London Borough of Haringey Central Library holds the ASLIB GUIDE TO BRITISH THESES and also THE TIMES INDEX, both of which were searched. The University of London's INSTITUTE OF EDUCATION LIBRARY was also extensively used. Manual searches were made through COMPREHENSIVE DISSERTATION INDEX and other reference sources. A list of indexes, guides and journals which were searched is included after the bibliography.

2.1.3 OBSERVATIONS ON LITERATURE SEARCHING

Although it was not necessary to make a comprehensive search of every aspect of graphical communication, child development, learning theory and computers, the writer thought that it would be unwise to forego the opportunity to collect references to any aspect of teaching graphical communication that would be useful. On reflection, it would seem desirable that any teacher who has responsibility for a subject should have access to online literature searching, and that all teachers should be taught during their initial training the essentials of literature searching.

2.1.4 ORGANISATION OF THE LITERATURE SEARCH

Since a number of observations which are made in the review of literature on technical drawing and computer graphics only make sense after presenting an analysis of three-dimensional descriptive geometry, it was decided to split the presentation of the literature search into three parts.

Chapter 2 is devoted to a review of the literature of child development and theory of education. Chapter 3 consists of an analysis of descriptive geometry. Chapter 4 reviews the research into technical drawing and computer graphics.

2.2 CHILD DEVELOPMENT

2.2.1 JEAN PIAGET

The Swiss psychologist Jean PIAGET and his associates in Geneva have accumulated since the 1920's the largest store of factual and theoretical observations on the development of cognitive processes in children ever undertaken.

PIAGET believes that the cognitive development of children proceeds in stages or periods which are based on maturation processes that every child must go through to become an adult. Naturally some children develop faster than others, but nevertheless, each will go through distinct periods of development characterised by changes in its thinking.

The periods of development are distinct because, according to PIAGET the child establishes a structure for thinking about its world based upon its capability for perceiving relationships, and driven by a need to create a stable system for reacting to the world. When through new experience and maturation the existing structure becomes too inconsistent, a new structure is created, this too remains relatively stable until it to becomes untenable.

Each period of development incorporates additional strategies to process certain types of logical proposition into the child's cognitive system until the system is theoretically capable of faultless reasoning.

2.2.2 PIAGET AND MATHEMATICS

COPELAND (1979, p410) writing about the teaching (maths) implications of Piaget's research claims that for children aged 5 to 11 years of age the teacher is concerned with "developing knowledge of the physical world and logico-mathematical knowledge; but for the latter the child is limited developmentally or biologically speaking in that he does not develop certain thought structures for abstract logical and mathematical reasoning until about 12 years of age." The same work contains a useful appendix (page 414) detailing the ages at which mathematical concepts develop, three periods are listed: late Preoperational (4-7), Concrete Operations (7-11) and Formal Operations (11-15).

The mathematical concepts that are necessary for understanding the representation of three-dimensional objects, include the the coordination of the horizontal and vertical and the notion of geometrical projection. PIAGET considers these concepts to become part of the child's cognitive system during the late concrete operational period and the period of formal operations respectively.

2.2.3 AGE AND DEVELOPMENTAL PERIODS

The present study involved children aged 11 to 17 years of age; some of the younger children should, according to PIAGET, be entering the third period of development - the period of formal operations (11-15). However there are studies (quoted by PHILLIPS 1975) that suggest Piaget's norms for the achievement of formal operations are high compared with British and American children (LOVELL and BUTTERWORTH 1966, DULIT 1972, FRIOT 1970, KARPLUS and KARPLUS 1972, KARPLUS and PETERSON 1970, McKINNON and RENNER 1972, ROSS 1973) "In every one of these studies, the age suggested by PIAGET is, it is argued, too low, and many individuals have failed to reach the formal level at any age" (PHILLIPS 1975 p170). SHAYER & ADEY (1981) report the findings of their extensive survey of British school children, showing that a majority of adolescents have concrete operational ability whilst only a minority have achieved formal operations.

PIAGET'S theory of developmental periods has had to be further refined to take account of the anomalies raised by subsequent research, notably that a child may be able to demonstrate formal thinking in one content area but remain unable to rise above concrete operational thinking in another (PHILLIPS, 1975 pp.170-72).

PIAGET suggests that 'all normal subjects' become capable of formal operations sometime between the ages of 11 and 20, but they do so "in different areas according to their aptitudes and their professional specialisations, advanced studies or different types of apprenticeship for the various trades" (quoted in ibid, p.170). This could mean that some individuals may not be able to assimilate the concept of projection to any marked extent at all.

2.2.4 EDUCATIONAL IMPLICATIONS OF PIAGET'S THEORY

Although PIAGET did not construct an explicit theory of teaching his theory concerns intellectual development and is obviously relevant to teaching. According to PHILLIPS (1975, pp.141-6) there are three principles which can be derived from theory:

1. CONSTRUCTION THROUGH ACTION

 The child should be given an opportunity to discover relationships and properties by engaging in activities. For logico-mathematical knowledge situations should be devised to encourage the child to think about relationships. In general the teacher should encourage curiosity and the making of autonomous choices, for therein lie the foundations of cognitive structure.

2. TRANSFER AS SEQUENTIAL INTEGRATION OF STRUCTURES

 A cognitive structure is a more or less tightly organised system of mental actions. New inputs that are congruent with an existing structure are organised by it (assimilated to it). A structure (understanding, principle) then serves to organise new knowledge; conversely, the new situation may modify the structure.

3. MOTIVATION THROUGH COGNITIVE CONFLICT

 For a task to be suitable for engendering a qualitative change in the child's cognitive structure there has to arise a certain amount of conflict, an optimal discrepancy between environmental inputs and existing cognitive structure. If input is precisely congruent with existing structure, accommodation of the structure does not take place, and if the input does not fit the structure at all it is not assimilated. The teacher has to be particularly careful not to resolve a conflict by reason of his authority as although the child may come to agree he has not learned anything

> except to distrust his own judgement. The role of the teacher in developing logico-mathematical knowledge, then, is clearly not that of a dispenser. It is absolutely impossible to dispense logico-mathematical knowledge. The teacher's role is that of a guide not of a planned tour but of a genuine exploration. So far as possible, he is a consultant rather than an authority.

PHILLIPS (ibid, p.175) has expressed a dilemma which arises from applying Piaget's developmental theory to education it is:

"1. if a child is not ready to change, no teacher can help him;
2. if he is ready, the change will occur without intervention;
3. therefore, intervention is superfluous."

PIAGET does not reject this proposition, indeed he has stated that not only is intervention superfluous but actually harmful: "Every time you teach a child something, you keep him from reinventing it." (PIAGET,1967) There is an optimal time for the organisation of operations but the optimal is not the minimal. The time spent in "hatching an idea" in "simply going around in circles," makes the idea "more stable and fruitful in the long run." (ibid) Teachers should provide an environment that will maximise the chances for each child to have whatever experiences he or she can have at his or her current level of development, confident that when the child is ready to have a higher level experience he or she will do so without being pushed. (PHILLIPS, 1975)

Unfortunately there is a very real risk that important facts which provide a basis for making discriminations and forming concepts may not be learned at all if the child is simply left to explore and make discoveries. AUSUBEL (1961) called for a distinction between "reception" and "discovery" learning goals.

Reception learning is directed to 'the long term acquisition and retention of stable, organised, and extensive bodies of meaningful, generalizable knowledge' whereas discovery learning is more suited to the "growth in the ability to use this knowledge in the solution of particular problems, including those problems which, when solved, augment the learner's original store of knowledge." He argues that although there is some overlap, the two are distinguishable. Obviously it would take an unacceptable amount of time to "discover" the enormous amount of knowledge that must be acquired to provide a person with a good general education.

2.2.5 CRITICS OF PIAGET'S THEORY OF CHILD DEVELOPMENT

In addition to the above reservations there is criticism of Piaget's findings. FREEMAN (1980, p.40) argues that: 'there is no direct access to representations in the mind'; the graphic, verbal and physical activity of the child under observation are subject to interpretation which require theory that PIAGET has neglected to utilise or develop: in particular, human performance theory and theory of graphic representation (ibid p. 210), without which the task of interpreting children's drawings in terms of their cognitive development becomes questionable. It is not disputed that children find great difficulty with spatial problems, what is disputed is why they have difficulty. As Freeman so aptly puts it: 'There is all the difference in the world between a theory which says that the child fails because he lacks the necessary ability and one which says he fails because he does not know how to use what abilities he has in different situations.' (ibid, p.68).

BRYANT (1974) also found fault with Piaget's interpretation of childrens' behaviour by showing that children as young as four could make a deductive inference provided they were given all the information needed to solve the problem.

PIAGET's theory asserts that the child reasons by means of his or her logical structure which itself develops by experience of a world which is ordered. If young children can reason transitively, as Bryant asserts, then the logical structure is there, virtually complete, and it is other factors which prevent a child from making a correct interpretation of its experience.

BRYANT supports his theory with data gained from experiments, he states that development is dependent on the establishment of absolute codes: ' Young children can on the whole remember relative values with great ease, but have problems in situations in which they must remember absolute values.' (ibid, p.14) He argues that although adults have similar difficulty with remembering absolute values the problem is particularly pronounced in young children. 'Children take a long time to develop absolute codes and some possibly may not acquire such a code at all. . . Young children have considerable difficulty in understanding the rules governing their environment simply because they cannot remember the absolute properties of objects around them, and that as they grow older they begin to develop some strategies for coping with them. This "absolute" development is never complete, and its extent varies between continua.' (ibid, p.14)

According to BRYANT children rely on the use of relative coding to register relations between different objects presented simultaneously. Objects that are presented at different times can be compared by considering their relationship to a common framework. They do make deductive inferences, indeed BRYANT argues that the child's basic tool for organising his or her perceptual experiences and learning from them is the deductive inference, but they are often at a loss if they have to actively seek for the relevant information. Older children and adults who have not developed absolute coding, must also resort to making comparisons between an object and its framework in order to solve the problem of connecting past with present experience.

2.2.6 EDUCATIONAL IMPLICATIONS OF BRYANT'S THEORY

BRYANT has shown that quite young children can make deductive inferences but they are severely limited by their lack of ability to use an absolute code. For BRYANT, development involves the establishment of absolute codes.

Although BRYANT does not provide any guidelines for teachers, it would seem reasonable to conclude that teachers need to compensate for the pupils' level of development, by supplying or designing instructional materials and providing learning activities which take account of the individual pupil's attainment of absolute coding, eg measurement. Great care will need to be taken to provide all relevant information to solve any given problem and supply some form of reference framework to facilitate the use of relative coding to make deductive inferences. Computer-generated reference frameworks are possible and some use has been made of them in this study (see Chapter 8 section 8.8).

2.3 EDUCATIONAL THEORY RELEVANT TO THE STUDY

2.3.1 INTRODUCTION

2.3.1.1 LEVELS OF DEVELOPMENT AND TEACHERS' STRATEGIES

Whatever the reasons may be for children having difficulty with certain types of problem, what is not disputed is that they do have difficulty. The child's level of cognitive development, whether interpreted according to Piaget's theory or not, needs to be taken into account by teachers. Certain strategies which teachers may employ are more likely to be effective if they are matched to the individual child's level of development and personal experience.

2.3.1.2 STRATEGIES AND LEARNING THEORY

For a strategy to be effective it must be based on some theory, or philosophy of learning which is viable. For example EGGEN, KAUCHAK and HARDER (1979) identify six strategies which teachers may employ in teaching virtually any subject; these strategies are based on the learning theory of Ausubel, Bruner, Suchman, and Taba. The designer of instructional material is more likely to produce useful material if care has been taken to follow the findings of researchers in the field, rather than model the instruction on existing material, which although usable can be regarded poorly by teachers and pupils alike. It is therefore important to investigate to what extent the strategies which have been developed for teaching drawing are based on or can be related to psychological theories of learning. It would also be unwise to incorporate certain methods which are used in the teaching of technical drawing into the computer without a reappraisal of their effectiveness.

2.3.2 PSYCHOLOGICAL THEORIES OF LEARNING

2.3.2.1 THREE MAJOR THEORIES

LEFRANCOIS (1972, P.310) divides the theory of human learning into two broad orientations which give rise to the classical divisions among psychological theory. The first orientation assumes that human behaviour is at least in some measure influenced by what goes on in the brain. The second whilst not contradicting the first, asserts that very little knowledge which is scientifically valid can be derived from an investigation of thought and feeling. The prebehaviourists and the cognitivists have the first orientation in common, the behaviourists and neobehaviourists the second. Lefrancois points out that such terms are for convenience, as few positions are clearly only behaviouristic or cognitive. In addition the labels indicate different areas of interest. The three major divisions are: Behaviourism, Neobehaviourism, and Cognitivism. The latter position is of more interest to this study as cognitivism concerns the more central processes such as problem solving, perception, decision-making, information processing, and concept formation.

2.3.2.2 ROBERT GAGNÉ

In the final chapter of his book Lefrancois presents the case for an integration of the learning theories which he has reviewed (ibid). In particular he cites Robert Gagné (1965, p.70) as having produced a detailed and comprehensive integration of knowledge about human learning. Gagné describes eight types of human learning, each relating to one or more theories of learning. Lefrancois stresses that the learning types are not completely independent from one another but are in fact hierarchical.

A second point Lefrancois makes is that these types of learning are distinguishable largely in terms of the conditions that permit the learning to take place. Gagné's classification of types of learning is best presented as a table (Appendix 1, table 1)

The quality of the teacher's instructional materials and teaching depend therefore on the extent to which they provide the appropriate conditions under which learning may take place.

2.3.3 GAGNÉ'S THEORY OF LEARNING FOR INSTRUCTION

2.3.3.1 INTRODUCTION

The following theory of learning for instruction is drawn from GAGNÉ's book (1975). Gagné is an acknowledged authority in the field of learning theory for instruction and has, as already been noted, striven to integrate the findings of several psychologists into useful manuals for undergraduate and graduate students of education. It is of course important to be able to refer research observations and decisions back to an established theory of learning rather than have to engage in lengthy explanation.

2.3.3.2 THE IMPORTANCE OF THE TEACHER

GAGNÉ (1975) believes that because teachers often plan lessons that include material they develop and create they should have knowledge of learning principles and theory. The teacher is a **designer** and a **manager** of instruction and also an **evaluator** of student learning. One of the aims of this study is to provide teachers with a computer-based facility to design and manage instruction, a facility which it is argued has not been developed to any extent yet.

2.3.3.3 THE COMPLEXITY OF THE LEARNING PROCESS

Gagné posits the view that learning is a process similar to other biological processes, but is only partially understood at present as it is an enormously complex process. GAGNÉ's definition of learning is that 'it is a process which enables a living organism to modify its behaviour fairly rapidly in a more or less permanent way, so that the same modification does not have to occur again and again in each new situation.' (ibid, p.5) Learning has happened if behavioural change can be noted and this change persists.

2.3.3.4 THE PHASES OF LEARNING

The learning process consists of phases which serve to relate the internal processes to the external events that constitute instruction. The phases are **motivation, apprehending, acquisition** (the essential learning incident), **retention, recall, generalisation, performance**, and **feedback.** The corresponding internal processes and influencing external events are best presented in the form of a table (Appendix 1, Table 2). The influencing external events when planned for the purpose of supporting learning are called **instruction.**

2.3.3.5 HUMAN CAPABILITIES

Learning is a process activated by a variety of kinds of stimulation from the learner's environment. This stimulation is the **input** to the processes of learning. Their **output** is a modification of human behaviour that is observed as human performance. The kinds of performance that are seen as evidence of learning are many and varied, yet it is possible to classify them in order to contribute to our understanding of the learning process. The classification is based on the establishment of persisting states, the result of learning, which is evident in some kind of performance; these persisting states are called **capabilities,** a word that implies that they make the individual capable of certain performances. There are five major categories of learned human capability they are: **verbal information, intellectual skills, cognitive strategies, attitudes** and **motor skills**; there is no significance to be attached to the order presented here.

Although there are greater amounts of systematic knowledge available about some of the capabilities than others, the distinctions between them are dependably clear.

2.3.3.5.1 VERBAL INFORMATION

The learning of verbal information as a capability means that the individual is able to **state** in a propositional form what he has learned. The enormous store of information which most of us possess provides almost limitless possibilities for flexible thinking.

2.3.3.5.2 INTELLECTUAL SKILLS

This capability is, simply stated, **knowing how** as contrasted with the **knowing that** of information. Someone that has acquired an intellectual skill can **demonstrate** its application to one or more particular classes of phenomena to which it refers.

Intellectual skills are acquired by means of symbols, the symbols include letters, numerals, words, and pictorial diagrams of many kinds.

Intellectual skills vary in complexity from discriminations, to concrete concepts, defined concepts and rules, and to higher-order rules. They also **build upon** each other, in the sense that simpler ones are prerequisites for the more complex skills. This ordered character of intellectual skills has definite implications for their learning.

2.3.3.5.3 COGNITIVE STRATEGIES

The learner makes use of this capability in **managing** the processes of learning (as well as retention and thinking). Intellectual skills enable the learner to deal with numbers, words, and symbols which are "out there" whilst cognitive strategies govern the **learner's own behaviour** in dealing with his or her environment. Cognitive strategies are very important as they are used in thinking about what has been learned and in solving problems.

2.3.3.5.4 ATTITUDES

An attitude is an **acquired internal state that influences the choice of personal action.** Attitudes are related to **values,** but the latter are more specifically oriented to particular preferences. Attitudes are also referred to as the **affective domain** Attitudes, as learned capabilities have a behavioural effect in that attitudes affect human performance.

2.3.3.5.5 MOTOR SKILLS

The function of motor skills as learned capabilities is readily evident. They make possible the precise, smooth, and accurately timed execution of performances involving the use of the muscles. Although not the most prominent part of educational goals they must be included as essential capabilities.

Motor skills are especially inportant in the area of teaching technical graphics, as whilst it can be argued that it is possible to learn the subject without getting deeply involved in producing drawings in practice it is difficult to maintain interest when a theoretic approach is adopted. An improvement in the student's ability to draw, both freehand and with instruments, is generally regarded as an important educational objective. However as pointed out in section 1.1.5 poor drawing skills often result in a reduction in attention when areas which are important to the development of the other capabilities are being dealt with.

The investigator has had, on occasion, to resort to locking the instruments away in the store in order to ensure that the group devote more of their attention to a demonstration, lecture, or discussion. Typicallly the strategy adopted is to mention that an important topic is going to be discussed next lesson, and before the next lesson commences remove the instrument trolley etc before the pupils arrive.

These five major categories of learned capabilities represent categories of **what is learned** how they are learned is dealt with in the next section.

2.3.3.6 THE CONDITIONS FOR LEARNING

The conditions for learning deal with **how** learning can be supported. The events which promote learning both within and outside the learner constitute the **conditions for learning.**

The objectives for learning need to be specified exactly so as to ascertain what type of learned capability is required. A statement of an objective for learning consists of three parts: the **situation** confronting the learner, the **outcome performance** and the **action** specified to indicate the particular form the performance is to take. The outcome performance corresponds to one of the five major types of learned capability and is denoted by a verb. GAGNÉ stresses that the verb has to be unambiguous, as the main idea is to communicate what kinds of human capability is to be learned. The particular verbs which he considers to be admirable for the purpose are listed in Appendix 1, Table 3.

The result of learning is the acquisition by the learner of a capability which must belong to one of five categories of learning outcome. The learner must pass through several phases during the learning process which correspond to internal processes in the individual's central nervous system. The phases are **motivation, apprehending, acquisition, retention, recall, generalisation, performance, and feedback.** To each category of learned capability there are a set of conditions which support the learning process in each phase. Each set of conditions for the promotion of the learning through its several phases toward accomplishment of the specified capability,constitutes a body of knowledge that is accumulating at varying rates, much is of direct practical use but only the most critical learning conditions, adapted from Gagné (1975), can be mentioned here:

SUMMARY OF CRITICAL LEARNING CONDITIONS

VERBAL INFORMATION

1. Activating attention by variations in print or speech
2. Presenting a meaningful context (including imagery) for effective coding.

INTELLECTUAL SKILL

1. Stimulating the retrieval of previously learned component skills.
2. Presenting verbal cues to the ordering of the combination of component skills.
3. Scheduling occasions for spaced reviews.
4. Using a variety of contexts to promote transfer.

COGNITIVE STRATEGY

1. Verbal description of strategy.
2. Providing a frequent variety of occasions for the exercise of strategies, by posing novel problems to be solved.

ATTITUDE

1. Reminding learner of success experience following choice of particular action; alternatively, insuring identification with an admired "human model".
2. Performing the chosen action; or observing its performance by the human model.
3. Giving feedback for successful performance; or observing feedback in the human model.

MOTOR SKILL

1. Presenting verbal or other guidance to cue the learning of the executive subroutine.
2. Arranging repeated practice.
3. Furnishing feedback with immediacy and accuracy.

GENERALISATION OF THE CRITICAL LEARNING CONDITIONS

There are at least four general ways of influencing the learning processes:

STIMULATING RECALL

Sometimes the external events accomplish their purposes by stimulating the learner to **recall** and **retrieve** something previously learned. This may be done by giving a single reminder, or by asking the learner to reinstate something that has been learned. **Recall** may be necessary for any particular instance of learning.

The computer programs which were devised during the period of this study require a certain amount of geometric knowledge if mistakes are not to be made. By selecting objects that the student finds interesting, the student is motivated to recall his or her knowledge of solid geometry. When the student finds difficulty with recalling what is meant by, eg 'a prism', printed reference material may be made available or an illustrated computer-based dictionary could be invoked by the student, or both may be used.

DIRECT PRESENTATION OF STIMULATION

Naturally the environmental stimulation inherently involved in the learning task must be directly presented to the learner. Varied stimuli (underlining, coloured printing) may be presented to suggest ways of coding the information to be learned. Verbal or pictorial cues may be given to support the retrieval of what has been learned.

It is argued in Chapter 5 that it is desirable to provide the student with a model which directly stimulates his or her understanding of spatial relationships in order to learn how to represent them graphically. This model it is argued, needs to be provided with cues relating to direction, and with annotation, which the teacher may use to communicate with the student.

ACTIVATION OF A MENTAL SET

A set is usually induced by verbal instructions. It selectively activates processes of learning and performance. The learner is directed to pay more attention to some aspect of the situation because a mental set has been established.

The relatively labour-free production of a variety of different views of an object that the computer generation of illustration provides enables a teacher to be more selective in his or her use of illustration. It is therefore, feasible to decide which type of illustration needs to be generated in order to establish a mental set for various learning objectives.

PROVIDING FEEDBACK

Every act of learning requires feedback if it is to be completed. If the feedback is not automatically provided by the performance provision has to be made to communicate the outcomes of a performance as accurately as possible.

Computer programs that are designed to enable students to design objects provide opportunities for feedback in that the computer realises the student's design as a computer-generated drawing. It is argued in Chapter 5 that students derive geater satisfaction from this type of feedback than from a teacher.

2.3.3.7 CONCLUDING REMARKS

Gagné's theory of learning for instruction provides a means to promote learning, as it is an integration of what is known about learning and teaching. The various recommendations may be used to analyse existing instructional materials, support the design of new materials, and improve the teacher's effectiveness.

CHAPTER 3

THE NATURE OF THREE-DIMENSIONAL PRACTICAL DESCRIPTIVE GEOMETRY

3.1 THE LITERATURE SEARCH

Practical descriptive geometry is the science upon which engineering graphics is based. The bulk of the literature is therefore located within the broad field of engineering graphics education. The search was restricted to research in English speaking countries. The author has been unable to trace any research in the United Kingdom above Masters level in the engineering graphics area and very little at that level. No references were found for Commonwealth countries in the Lockheed Dialog databases, Aslib Guide to Theses, and the various books, periodicals and theses consulted. It follows that unless otherwise stated the references are to American research. Very little of the research was carried out at the secondary school level.

Research related largely to the analysis of practical descriptive geometry is reviewed in this Chapter. Teaching methods and media are reviewed in Chapter 5.

3.1.1 CONCEPTUAL HIERARCHIES & SCHEMES OF WORK

A primary aim of the literature search was to establish whether descriptive geometry had been analysed and arranged into a conceptual hierarchy. This knowledge is important for a number of reasons. First, such an analysis is a prerequisite for constructing a learning hierarchy, which is essential for identifying which skills are needed to demonstrate mastery of a concept. Second, a conceptual hierarchy can be used to ensure that the sequencing of instruction is free from logical inconsistency. Third, the analysis of the subject provides a means to diagnose individual difficulty with great accuracy. GAGNÉ (1974, p.48)

Despite an intensive search no reference to conceptual or learning hierarchies and schematic learning could be found for descriptive geometry. The parameters of the search were widened in the hope that useful material might be uncovered. Although a wider search resulted in locating material that was of interest, no evidence could be found that anyone had set out to analyse descriptive geometry or selected topics of the geometry into its component concepts.

Research on developing schemes of work has been undertaken notably by SCHWEINFURTH (1969) and HORTON (1980). Horton's program identifies components of a complete course in engineering drawing that instructors and industrial representatives considered to be important.

SCHWEINFURTH (1969) produced a model program for teaching engineering graphics. His program was developed from a list of behavioural objectives that were evaluated by a panel of experts in educational technology and engineering graphics. Since the sets of goals and objectives presented in the study can be utilised in the classroom in any order, Schweinfurth recommended that further study should be devoted to determining the best sequence for learning efficiency either emipirically or theoretically. He also recommended that media and methods best suited for the presentation of material geared to the attainment of the goals should be determined (ibid, p.70).

3.2 THE DEVELOPMENT OF DESCRIPTIVE GEOMETRY

3.2.1 ORTHOGRAPHIC PROJECTION

Although the drawing of plans was in use in Babylonian times the technique known as orthographic projection was not developed until the Sixteenth Century. Plan and elevation drawings, although in use in mediaeval times, were not projections as such, but were true shape pictures and were often coloured and shaded. Albrecht Dürer (1528) made some very fine engravings of heads and other parts of the human body to accompany a book on the proportions of the human figure. The illustrations, which can be found in BOOKER (1979, p.43), consist of three or more related orthographic views arranged in projection, a superimposed grid of lines emphasising various proportions extends from one view into the next related view. These illustrations exemplify Dürer's grasp of orthographic projection. However there was no necessity at that time to investigate the underlying theory. It was not until the advent of the industrial revolution that the learned Frenchman Gaspard Monge developed existing orthographic techniques into the comprehensive theory which is known as descriptive geometry.

3.2.2 GASPARD MONGE (1746 - 1818)

Gaspard Monge started his career in the fortification design office of the school for army officers at Mézières in the Ardennes. In a short period of time Monge developed novel and more efficient geometrical methods for solving complicated problems in the design of fortifications. The Commandant recognized Monge's worth and he was taken out of the drawing office to become at first the pupil and later the assistant to the professor of physics.

At Mézières there were schools of carpentry and stone cutting, as most of the military works of that time were still mainly made of wood and stone. He analysed and introduced improvements in the graphical methods that were used by the workmen. During this time he accumulated enough material to publish a book, but the authorities considered that his work was too valuable to be made public and classified it as a military secret. It was not until 1795 that Monge was allowed to publish his book 'Géométrie Descriptive'. In the meantime he had become a member of the Academy of Sciences, a Minister in the Revolutionary Government and had a leading part in the development of educational reform.

France had to depend upon foreign countries for many of its manufactured goods. Monge and his colleagues successfully promulgated the view that France needed to improve industrial education; an Act was passed, and in 1794 the Ecole Normale was opened. The Ecole Normale was essentially a training school for teachers who would, given the right sort of education, be able to educate the rising generations according to the needs of the new age which was dawning. Descriptive geometry was considered from the outset to be a key subject in the curriculum of the Ecole Normale. BOOKER (1979, p.86-106)

3.2.3 MONGE'S DESCRIPTIVE GEOMETRY & ORTHOGRAPHIC PROJECTION

Monge's theory is based on the notion of two mutually perpendicular projection planes, one of which is vertical and the other horizontal. An object is placed in the angle made by the two planes and images are imagined to be projected onto the planes. The image projected on to the vertical plane is referred to as an elevation. The image projected onto the horizontal plane is referred to as a plan. To obtain a graphic representation of the object it is necessary to imagine the image planes to be rotated into the same plane as the paper.

These two images are sufficient to represent the shape and form of any object that could be constructed of horizontal and vertical rectangular surfaces. The drawing that results is identical to an orthographic representation, but the concept provides a framework for tackling more intricate spatial problems. Objects with sloping or inclined surfaces need in addition, concepts that enable the inclined surfaces to be extended to intersect both the vertical and horizontal reference planes. The lines of intersection are referred to as the 'traces of the plane'. Depending on the inclination of the plane to the reference planes, one of the traces is considered to be an axis around which the plane is rotated into the reference plane. Since an image of the surface lies on the plane it will be projected into the reference plane. The two reference planes have as before to be rotated into one single image plane before a graphical representation can be made.

Geometric constructions to find the true shape of inclined surfaces existed and were in use, but Monge's theory created a synthesis of geometric techniques and orthographic projection so that spatial problems could be solved more directly.

3.2.4 MODERN DESCRIPTIVE GEOMETRY

3.2.4.1 THE AUXILIARY VIEW CONCEPT

There is a disadvantage in using pure Mongean methods. The points and lines representing an inclined surface in its true shape have to be projected on to the main planes. The resulting superimposition of construction lines on the outlines of the object add to the drawing's complexity. Leighton Wellman (1949) considers that the 'resulting network of lines frequently becomes confusing even to the expert draughtsman. To the perspiring student it becomes hopeless.'

It was not until the latter part of the nineteenth century that an alternative method to the Mongean plane trace method of finding the true shape of an inclined surface was developed. It was discovered that it is possible to project an additional (auxiliary) view normal to a sloping surface and so gain a true representation of that surface's shape. One of the principal advantages of auxiliary views is that they can be positioned a convenient distance from the main views, thus ensuring that there is no overlapping.

WLADAVER (1950) carried out an experiment to determine whether the plane trace method was less effective than the edge-view (auxiliary view) method in the teaching of descriptive geometry. He found that although the auxiliary view method was slightly more effective, it could not be claimed that the auxiliary method was generally superior.

However the exercises that the students had to solve involved simple objects and the possible confusion which according to WELLMAN (1949) arises in employing the plane trace method would tend to be reduced. It is likely that a similar experiment with more complicated objects to draw would favour the auxiliary method.

Wladaver's research required a survey of colleges to ascertain the extent to which each method was taught. Vary rarely were both methods taught. The primary reason given for not teaching both methods was shortage of time. One college, despite shortage of time, taught both, as it was considered that a thorough understanding of both methods led to a greater understanding of descriptive geometry. Each method was taught fairly equally according to the preference of the instructor.

Wladaver's students were college age. There has been no research to ascertain whether secondary school age students would find the auxiliary view method significantly easier to learn than the plane trace method. It is probable that the auxiliary view method is an easier method for school students to learn as it is a more direct, more concrete method than the plane trace method.

Contemporary textbooks, both here and in the USA, favour the auxiliary view method. However the technique is not redundant as there is a certain utility in applying the plane trace concept to some types of problem see (SLABY,1979, p.217).

3.2.4.2 ARRANGING VIEWS

According to Monge's theory the horizontal and vertical reference planes divide space into four parts by creating four right angles. Each space is conventionally referred to as the 1st angle, 2nd angle, etc. Monge preferred the object to be thought of as being positioned in the 1st angle. The plan and elevation of the object will have to be arranged on the picture plane in projection with each other, so that the elevation is above the plan. A profile view can be projected, if necessary, to lie either to the left or right of the elevation.
Thus three views of an object can be projected onto the reference planes. If the object is placed in the 3rd angle the

plan will project above the elevation. The use of the other two angles results at best in the plan overlapping the elevation or at worst the plan overlapping and being turned upside down and mirrored, depending on whether the horizontal plane is imagined to be rotated down, so as to lie coplanar with the vertical plane, or up.

An alternative conception is to imagine the object placed within a glass box on to which up to six views can be projected. This idea was developed in the USA as a means to teach arranging views in 3rd angle projection. In Europe 1st angle projection has been standard up until recently.

There is little research on arranging views. In the UK, SPENCER (1965) carried out experiments on engineering drawing comprehension . He found that draughtsman found little to choose between 1st or 3rd angle projection, but university arts students of both sexes who were totally unfamiliar with engineering drawings found 3rd angle projection easier to understand. ABBOTT (1963, p.168) compares 1st and 3rd angle from the point of view of preparing illlustrations for textbooks. He argues that pictorial type illustrations of problems to be solved using 3rd angle projection are harder to understand than similar illustrations for 1st angle projection. (See Appendix 1, fig. 1-3.) Abbott's textbook uses pictorial type illustrations more frequently than most authors to convey the solution to spatial problems. However, American textbook illustrators seem to have overcome the problem. (See Appendix 1, fig. 4-8)

HOOD (1929) introduced the 'direct method' in his textbook the Geometry of Engineering Drawing. He argued that it is possible to dispense with planes of projection, and encourage the learner to think not of flat projections obtained by a difficult to imagine series of spatial operations on some three-dimensional image of the object floating in one of four angles created by two intersecting planes, but of the object itself. The student should think of viewing the object, which is considered to be stationary, from different directions. The main directions, which are related to our body, being: front and back, left and right, up and down. Each of the six views is constructed by drawing each surface of the object according to whether the surface is visible from the front, the left side, etc., bearing in mind the geometric attributes of the surface. The views are placed on the paper in the same relationship, the left side view is placed to the left of the front view, the right side view to the right of the front view, etc. (see Appendix 1, fig. 9.)

3.2.4.3 DEVELOPMENTS

An orthographic multiview drawing represents the form of an object precisely, but in order for it to be fabricated from sheet material a development of the object's surface has to be drawn. A development can be thought of as an 'unfolding' or 'unrolling' of the complete surface of an object so that it lies flat on the paper. Unless the object consists only of horizontal and vertical surfaces, it is necessary to use auxiliary projection or the plane trace method to ensure that sloping surfaces are correctly depicted. Geometrically complex objects consisting of interpenetrating solids, eg., a cone and a hexagonal prism, require an additional technique which involves sectioning the object by means of a series of parallel section planes in order to ascertain where one of the geometric solids penetrates the other.

Although some developments are very simple, the more complicated types require not only a thorough understanding of descriptive geometry but also a very high degree of draughting skill. See DICKASON (1967) and Appendix 1, fig. 10.

3.2.4.4 MISCELLANEOUS OPERATIONS

Over the years a variety of techniques have been developed for solving certain types of problem more easily. For instance, if the edge of a pyramid form is sloping in relation to the horizontal and vertical, it is often more convenient to rotate just the edge rather than the whole form into a horizontal or vertical position in order to obtain its true length. See Appendix 1, fig. 10-11. Rabatement is another technique that is commonly used; it is employed to find the true shape of a surface when it is unecessary to construct an anxiliary view. To rabate a surface it is necessary to imagine the inclined surface to be detached from the object except for one edge, the edge is then regarded as an axis around which the surface can be rotated until it is parallel to a reference plane. Projection onto the reference plane provides a true shape of the surface. The notion of edges about which surfaces can be rotated so as to lie in one plane, is also essential to understanding how to produce a surface development. These operations might seem simple but they necessarily involve a good grasp of spatial relationships.

3.2.4.5 HIDDEN DETAIL

The main views of an object together with any necessary auxiliary views are sufficient to ensure that all visible features of the design are represented accurately. If the object has surfaces which are not visible, the edges of the hidden surfaces are conventionally represented by a line made of short dashes.

A mental image of the object represented by orthographic projection has to be visualised by synthesising its geometric form from several orthographic views. Whilst the inclusion of hidden detail might be essential, the views can become extremely difficult to interpret. It is for this reason that conventional methods have been developed to minimise the use of hidden detail. Foremost among these methods is the sectional view. The object is imagined to be cut by a projection plane on to which a view of part of the object can be projected (3rd angle projection), or from which a view can be projected onto a plane behind the object (1st angle projection). Alternatively using the 'direct method', the object is imagined to be cut and part of it is removed so that a view can drawn of the previously hidden detail. See Appendix 1, fig. 13.

Conventionally, to distinguish the geometric features of the object where it is cut through by the section plane, 'hatching' is used. Hatching is a drawing technique where a new surface, the result of sectioning an object, is filled with a series of parallel lines drawn at an angle to the outlines of the object; these lines are drawn not less than 4mm apart and are half the width of the outline. See Appendix 1, fig. 14-15 for the various types of line and their application.

Sectional views may be taken at any convenient place, whilst the majority of sectional views are either horizontal or vertical it is sometimes necessary to draw auxiliary sectional views. A further complication is that it may only be necessary to draw a partial sectional view, see Appendix 1, fig. 16. All types of sectional view should if possible be arranged in projection, but sometimes due to lack of space a view may be placed in some convenient position, provided it is labelled.

Where a design concept consists of several objects which fit together, the orthographic views and sectional views which represent the design are referred to as an assembly. The component parts in a sectional view of an assembly are hatched in different directions in order to clarify their relationship to each other.

Sectional views, by definition, relate to an object or assembly which has been cut to show internal detail. Where the assembly consists of cylindrical components, eg shafts, bearings, nuts, bolts, etc it is better to only hatch the surfaces in which the rounded parts lie; this convention corresponds to display examples of sectioned assemblies where rounded parts are left intact. See appendix 1, fig. 13 and 17.

3.2.4.6 CONVENTIONS

The use of conventional techniques to improve the effectiveness of orthographic multiview drawings, as the medium whereby the designer represents his or her design concept, marks the boundary where descriptive geometry merges into engineering and architectural graphics.

A typical engineering type drawing drawn to British Standard 308 is included in Appendix 1, fig. 18. such drawings include dimensions and so represent a component exactly, but they are very abstract, especially to those who are not familar with orthographic views. It is because of this difficulty that techniques for constructing pictorial type views have been developed. (BS 308: Part 1: 1972, p.14.)

3.2.4.7 PICTORIAL VIEWS

Pictorial drawings, in contrast to orthographic views, convey a more vivid impression of a design concept than orthographic views. This is due to the more realistic appearance of the object. The most naturalistic pictorial view is the perspective view which is, within certain limits, equivalent to a photograph. The camera can only be used for recording the image of a design concept when it has become a reality; however, a naturalistic view can be constructed by the methods of descriptive geometry. The view can be coloured and shaded using an airbrush resulting in an image that can be superior to a photograph in some respects. Perspective views require substantial amounts of time to produce and for many applications a simpler type of pictorial view is not only sufficient but has certain advantages.

Perspective views are not to scale so they cannot be used to determine the dimensions of a feature. By comparison, since other types of pictorial view are created by applying a scaling factor to the three dimensions, it is possible to include dimensions. But the use of simpler pictorial views has certain disadvantages: some drawings frequently have a distorted, unreal appearance that is disagreeable; the time required for execution is, in many cases, greater than for an orthographic drawing; and some of the lines cannot be measured, adding to the difficulties of dimensioning the view LUZADDER (1968, P.270).

The simplest types of pictorial view are isometric and oblique. Isometric views relate to orthographic views in that they can be considered to be obtained by orthographic projection onto an auxiliary plane, however an isometric view can be obtained directly, although there is a slight disadvantage in that the resulting image appears larger than life. Apart from this minor distortion only the lack of perspective foreshortening detracts from the naturalness of the isometric view. Oblique views can be imagined to be produced by an oblique projection onto either a vertical or a horizontal plane, the latter case is commonly referred to as a PLANOMETRIC view. Oblique views can appear quite strange as unlike the isometric view there is no easy way to relate the view to the student's perception of an object.

Appendix 2, fig. 1-3. depict isometric, oblique, and planometric types of pictorial view.

These simpler types of pictorial view carefully selected can be particularly effective, they are used extensively for school textbooks, technical catalogues, instructional manuals, architectural interiors and furniture design, piping diagrams and various journals and newspaper articles.

Pictorial sectional views of assemblies are very important as a means of communicating technical information, such views are almost invariably isometric views and particularly with complex assemblies are barely discernable as a highly conventionalised type of illustration. Many of the problems in school and college textbooks use either isometric or oblique views as illustrations see for example MITCHELL's BUILDING SERIES (1983) in which nearly every illustration in all six volumes utilises either orthographic or isometric views.

All UK examination syllabuses in technical graphics type courses require students to be able to construct pictorial type views from orthographic views of an object. Isometric type views are common to every syllabus listed in: MYERSON (1986, P.4-5.). The use of pictorial views of objects from which to produce orthographic views is a common means of improving a student's ability to interpret spatial relations into the descriptive geometry representation.

3.3 ANALYSIS OF DESCRIPTIVE GEOMETRY

3.3.1 INTRODUCTION

An analysis of descriptive geometry is necessary in order to progress from the theory to the development of the means by which the computer can be utilised to generate didactic material. The computer is a machine, it can only do work by means of a program which has been written to accomplish some task. The results of running a program depend not only on the the program but also on the variety of information that can be input to that program. A program to produce an illustration requires a specification and it is convenient to regard the person who makes the specification and uses the computer to generate the illustration as the illustrator, whether he or she is a professional illustrator or not.

3.3.2 THE ILLUSTRATOR AND THE COMPUTER

Illustration for descriptive geometry textbooks involves drawing figures to accompany the text which refers to instructional material and student exercises. The illustrator creates the figures by drawing, whereas if the illustration were to be generated by computer, algorithms would be employed to generate specific geometric forms and carry out various geometric operations. According to the way the programs have been designed the user may have a greater or lesser amount of access to the geometrical operations which determine what can be drawn.

Given a sheet of paper, a pencil, and a few other inexpensive pieces of drawing equipment the illustrator is only limited by his or her geometrical knowledge, powers of visualisation, time, and drafting skill, whereas the computer, whilst offering considerable savings in time and other benefits imposes various restraints on the user. These restraints may enable certain types of illustration to be generated with a minimum of user effort. But the ideal program should provide in addition sufficent facilities to generate exactly what the illustrator requires for a particular appplication with a minimum of user effort.

3.3.3 ESTABLISHING ESSENTIALS

It seems reasonable to propose that the essential geometric forms and operations for the creation of illustration for teaching and learning descriptive geometry can be deduced at least in part from the terms used to communicate concepts in textbooks. A similar analysis of the ideas and methods that illustrators have used in various textbooks would provide information for writing computer programs to enable similar illustrations to be designed.

It is part of the purpose of this study to contribute towards the knowledge of these requirements by developing such programs. But it was not feasible to undertake a thorough enquiry into this specific problem at the time when the research was undertaken.

3.3.4 FUNDAMENTAL CONCEPTS

It is important to identify the most fundamental concepts on which descriptive geometry is based, as unless the student can understand these, little real progress can be made. WELLMAN (1949) presented a paper before the American Society of Engineering Education: Engineering Drawing Division, on this very question. He argued that many of the principles, eg., the arrangement of views, which we might consider to be basic principles are either secondary, or are used for our convenience. They are not essential, the criterion for which he defines as: if this particular principle is fundamental, then if it is removed, the whole science would collapse.

After a short but careful analysis Wellman finds only one concept to be truly fundamental, and that is the notion of parallel lines of sight. If the lines of sight are converging to a station or eye point a perspective view would result. Wellman's short paper does not discuss the relationship between a view produced by parallel projection and a perspective view. But it is this particular relationship which is at the heart of the problem of teaching the concept of an orthographic view. Baldly stated it is this: orthographic projection is a special case of perspective projection.

3.3.5 THE BASIC ELEMENTS

Solid geometry is wholly concerned with the geometric attributes of solids and the spatial elements that combine to form such solids. Plane geometry is not separate from solid geometry but for convenience the two are usually presented separately.

Projective geometry has arisen from studies in the theory of perspective drawing and the development of optical instruments; it is a branch of pure mathematics that provides greater abstractness to ordinary geometry and algebra.

Descriptive geometry utilises solid and projective geometry to enable spatial structures and geometric solids to be represented graphically. The basic elements of geometry are the point, line, surface, and solid. It is important to discuss the attributes that these elements have as unless they are properly understood concepts which build on them may be only vaguely understood.

3.3.5.1 THE POINT

According to HALL & STEVENS (1965): ' A point has position, but is said to have no magnitude. This means that we are to attach to a point no idea of size either as to length or breadth, but to think only where it is situated. A dot made with a sharp pencil may be taken as roughly representing a point; but small as such a dot may be, it still has some length and breadth, and is therefore not actually a geometrical point. The smaller the dot however, the more nearly it represents a point.' (p.2.)

3.3.5.2 THE LINE

'A line has length, but is said to have no breadth. A line is traced out be a moving point. If the point of a pencil is moved over a sheet of paper, the trace left represents a line. But such a trace, however finely drawn, has some degree of breadth, and is therefore not itself a true geometric line. The finer the line left by the moving pencil-point, the more nearly will it represent a line.' (ibid)

3.3.5.3 THE SURFACE AND THE SOLID

'A surface has length and breadth, but no thickness.' (ibid) Hall and Stevens do not provide a concrete example of how a surface might be approximated, they just simply state that: 'A solid has length, breadth, and thickness.' (p.2.) GRIFFITHS (1976) declines to even give a definition for a surface.

3.3.6 RELATIONSHIPS BETWEEN THE ELEMENTS

'Solids, surfaces, lines and points are thus related to each other: a solid is bounded by surfaces, a surface is bounded by lines; and surfaces meet in lines. A line is bounded (or terminated) by points; and lines meet in points.' HALL and STEVENS (1965, P.2.)

3.3.6.1 POINTS

The essential geometric points to be made available to the illustrator include points which belong to either of two categories of geometric structure: solids or projections.

The points associated with solids include: the centre points of the bases of cylinders and cones, the apex of a cone, the centre of a symmetric solid, the centre of a polyhedron's plane faces, and the corners or vertices of polyhedrons. In addition it is important to have access to points created by intersections of: a line and a solid, a plane and a solid, and two or more solids.

The geometric points associated with projection include: the eye or station point, with the possibility of the point being if not an infinite distance away at least a very great distance away; focal points, and vanishing points both on a horizon line and elsewhere.

3.3.6.2 LINES

The essential geometric lines to be made available to the illustrator include lines which belong as before to the concepts of solids and projection.

The lines associated with solids include: the lines which represent edges of surfaces, the contour lines of a surface, lines formed by the intersection of two or more solids, and symmetry lines of a solid including the axes of cylindical and conical solids.

The lines associated with projection include: axis lines that belong to a cartesian XYZ coordinate set up. the eye line or sight line, the horizon line, the ground line, the set of lines from each vertex or corner of a solid which collectively are known as projectors, sets of vanishing lines, and scale marked measuring lines. In addition they include the lines formed by cutting planes taken for the purpose of making a sectional view, or for establishing some of the set of points which belong to two or more interpenetrating solids.

3.3.6.3 SURFACES

The essential surfaces to be made available include: individual surfaces belonging to various solids, surfaces created by interpenetrating solids, and projection plane surfaces including sectional planes.

3.3.6.4 SOLIDS

The library of solids should ideally include facilities to generate all of the different types of geometric solid which can be defined in general terms. It should be possible to create non-specific solids with a minimum of difficulty.

3.3.7 ESSENTIAL GEOMETRIC OPERATIONS

The essential geometric operations are divided into two groups. The first group of operations can be classified into manipulations of the basic four elements: points, lines, surfaces, and planes. The second group of operations can be classified as projective.

Manipulative operations can be divided into operations that generate solids and operations that involve movement. The most important movements include: rotation of the four basic elements; displacement of an element relative to an XYZ cartesian coordinate set up, and along an angular path; and increase or decrease of the size of an object. Operations that can be used to generate new solids include cutting a solid into two or more pieces by a cutting plane or by the removal of a piece which is of definite geometric form, eg., a cylinder; and joining solids together to form a new solid.

Projective operations include: parallel projection to create an orthographic image of a solid, and conical or central projection to create a perspective image.

CHAPTER 4

REPRESENTATION

4.1 REPRESENTATION AND REALITY

4.1.1 INTRODUCTION

Chapter 3 dealt with the nature of the subject without investigating the relationship between the drawing and the object that the drawing is supposed to represent. This relationship is of crucial importance to the development of resources for learning the subject.

The student has to be able to somehow process his or her perception of the object to be represented so that a drawing can be made. If the student has a clear, correct perception of the object's form, and understands how to interpret his or her perception by means of a knowledge of solid geometry and the science of descriptive geometry, satisfactory work is more likely to be accomplished.

It is the task of the teacher to manage the resources for learning and the student's time in order that the student will produce satisfactory work. Although it is important that the student has learnt to use the equipment effectively, the process of abstracting geometric data from the object to be represented, and interpreting that data into orthographic or pictorial views is of paramount importance. It is, therefore, necessary to examine the fundamental concept of the orthographic view more closely in order to identify areas of difficulty.

4.1.2 ORTHOGRAPHIC VIEWS

The three dimensional form of an object is reduced by the methods of practical descriptive geometry to a two-dimensional image in the orthographic multiview drawing. This image is a graphic model of the object and as such retains those attributes of the object which serve to represent its geometric form. Notable absences are the effects of solidity due to the ambient light, and colours and texture due to the materials from which the object is made. At this level of abstraction the drawing has a certain clarity. But the main purpose of producing orthographic drawings is to enable a design to be realised as a manufactured object. The designer will need to add relevant information to the drawing, this information will be coded according to relevant British or other Standards. The resulting drawing is thus a product of a mixture of a pure logical geometric mode of reasoning, and the application of conventions which have in some instances little relationship to reality, but nethertheless are meaningful.

4.1.3 PROBLEMS ASSOCIATED WITH ORTHOGRAPHIC DRAWINGS

LANER (1956) proposed that pictures, although popularly associated with a high value in communication as expressed in the saying: 'a picture is worth a thousand words',are in fact virtually meaningless unless supported by text or verbal commentary. The designer's orthographics are different in some respects from pictures, in that being highly conventional the code employed substitutes for the role of verbal language in the communication. It is not merely a figure of speech of instructors of technical graphics that they refer to the activity of interpreting a drawing as: 'reading a drawing'.

In a study carried out by SPENCER & CHENEY (1971) it was found that the time required for interpretation of a fairly complicated dimensioned orthographic drawing has been estimated to be on average one hour, even though about 80 per cent of the features on such drawings consist typically of cylindrical holes and also 10 per cent of the features are flat surfaces. The difficulty is due to a combination of errors caused primarily by misinterpretation of dimensions and to a lesser extent by faulty visualisation. The subjects involved in Spencer and Cheney's experiment were not only shop floor personnel but also draughtsmen, a fact which is rather suprising as draughtsmen must spend a considerable amount of time interpreting drawings.

In the same report reference is made to estimates that up to 70 per cent of the scrap produced by the engineering industry is attributable to errors in drawings or extracting information from drawings. Spencer and Cheney's enquiry centred on the numerical information content of engineering drawings, as dimension lines and section lines can be so close as to lead to error, they recommended an alternative method of dimensioning drawings. At that time development in the computer generation and storage of drawings was in its infancy. Today a drawing stored on computer could be inspected at different levels of enlargement and pictorial views could be used to assist visualisation.

In addition to the problem posed by possible human error due to misinterpretation of fine detail and visualisation, there is a more fundamental problem rarely mentioned in the literature, and that is that orthographic views may be ambiguous. WESLEY and MARKOWSKY (1981) developed and implemented an algorithm for finding all possible solids from objects with a given set of vertices and straight lines edges (its wire frame). The algorithm works for solid polyhedral objects with a given set of two-dimensional projections. The projections may contain depth information in the form of dashed and solid lines, may represent cross sections, and may be overall or detail views. The study is important for practical applications in the automatic conversion of digitized engineering drawings into solid volumetric representations of the geometry of objects, which become the basis for the simulation and synthesis of large parts of the design validation, analysis, manufacture, inspection, and documentation process.

In the report the authors show that even three orthographic views of an object may be ambiguous. One of the many examples illustrated, an octahedral like solid yields 35 solid objects, although most of the solids are improbable in that there are surfaces which have some edges which are unconnected to another surface. Such solids are similar in some respects to origami objects. The fact that there is in some cases more than one possible solid which can be represented by a single three view drawing has to be balanced against the probability of such an ambiguous drawing being produced. It is improbable that a professional draughtsman is likely to produce orthographic drawings with insufficient information, but possible. Pupils are quite likely to produce inadequate drawings, in fact part of the task of the teacher is to develop the pupil's ability to decide whether two views are sufficient, not only mathematically sufficient, but also sufficient in terms of good graphic communication.

Wesley and Markowsky's algorithm is based on formal geometric definitions and the concepts of algebraic topology. The computer program automatically generates possible solids from two or more orthographic views. They note that if the drawing is 'labeled' in the sense that hidden edges are dashed and other edges are thicker, ie., to Standard conventions, the number of possible solids is significantly reduced. The student of descriptive geometry, however, has no such flawless algorithm (cerebral variety) to employ to develop their work or to check it. Unfortunately, programs based on Wesley and Markowsky's algorithm were unavailable for this study.

Of particular interest to an understanding of difficulties that students have with correctly interpreting orthographic multiviews, is Wesley and Markowsky's observation that:

'In some cases, particularly where there are high degrees of symmetry and a limited number of views, giving rise to many highly correlated uncertain edges, there may be a very large number of objects producing the given projections.' (p. 945)

This observation leads to the notion that objects which have a higher degree of symmetry have a higher degree of possible uncertainty, and hence confusion for pupils, when represented by means of an orthographic multiview.

Gagné's table (Appendix 1 table 2) suggests that one of the influencing external events for supporting the apprehension phase of learning is: 'added differential cues for perception'. Applying this theory, the learner when confronted with orthographic views of highly symmetrical objects may fail to apprehend the form of the object because of a reduction in differential cues for perception,

Examination courses require teachers to teach practical solid geometry. The simplest solids, are by definition solids with a high degree of symmetry. Such solids are fairly common in manufacturing and building construction not only as single forms but also in combination, either as surface-to-surface assemblies or as interpenetrating forms; the latter are difficult to model, and there are no commercially produced sets of such interpenetrations. The high level of symmetry of simple objects enables drawings to be completed with a minimum of technical difficulty, as in many instances the construction involves the straightforward division of circles, but unless there is understanding of the underlying spatial relationships little progress will be made. This investigation has revealed no research on levels of understanding of orthographic drawings of symmetrical solids, compared to solids with reduced symmetry. It is difficult, therefore, to assert that the degree of symmetry of a solid is a problem, yet personal observation over many years leads to an increasing conviction that symmetry is an important factor in the teaching and learning of descriptive geometry.

Wesley and Markowsky's observation that the level of uncertainty in a multiview drawing is tied to high levels of correlation, eg., edges hiding edges, edge as the join of two surfaces or edge as the contour of a plane surface, is a crucial factor of the interpretation of orthographic views. This factor may be assigned to the set of attributes that are intrinsic to the drawing. In addition to the drawing there is the object which the drawing is supposed to represent, and the observer. If the drawing is a complete representation of the object, complete in the sense that there are a sufficient number of views to uniquely determine the object, then if there is still uncertainty leading to faulty visualisation it must be due to human error.

A computer program may be used to find whether a multiview drawing is ambiguous, and if it is to display possible solutions. If there are many possible solids to match a given multiview the program will find them all but it may take a considerable time. The pupil, however, may on occasion find a drawing confusing not because of an ambiguity, but perhaps because of a failure to take account of the facts presented by the views, the pupil's reasoning is faulty. In addition, the level of symmetry of an object may confuse the pupil's sense of spatial relations, left from right, top from bottom.

In every mixed-ability teaching group there are nearly always several pupils who have obvious difficulty with visualising the spatial relationships that a multiview drawing of a symmetric solid represents. The progress that is made is often so inadequate that it precludes the possibility of exploring variations in geometric form as would be desirable, for instance, for a project on roof design. The teacher cannot easily start with solids, which are less regular to avoid the potential confusion associated with solids with high symmetry, as these are usually harder to draw. And so there is a dilemma, lack of pupil drawing skill effectively prevents the teacher giving pupils the opportunity to get involved in some topic, which is not only more interesting, but also more likely to promote learning. By the time the pupils have achieved competence with instruments, there is insufficient time to devote to exploring the ways in which geometric forms can vary by means of drawing.

It is of course possible that an individual teacher or group of teachers could develop material to enable pupils to gain understanding of the manner in which variations in geometric form can be made, without the necessity for pupils to construct drawings. Approaches might take the form of pupils making models, manipulating developments, studying drawings, viewing slides, cine film and videos. But regardless of the resources which a teacher might employ, the pupil must eventually construct drawings, and as will be discussed below there is a substantial gap between 3D models and photographic examples and drawings. It will be shown further that this gap can be made smaller by means of computer-generated illustration. Computer programs that can be used to ameliorate the retarding effects of work with solids of high symmetry have been developed, these are discussed below (Chapter 6)

4.1.4 OTHER METHODS USED IN REPRESENTATION

An orthographic drawing is one method used to represent an object. It is more convenient than making a three-dimensional model but has several disadvantages that have been discussed above. In the workplace the orthographic drawing(s) of a machine part that is to be made, are accompanied by a production engineer's analysis of the steps necessary to manufacture the part - the work schedule. The machinist not only has the benefit of the work schedule but also can, if necessary, ask for advice from a colleague, the chargehand, or the foreman, who might consult the production engineer. Difficulties in interpretation might also be referred to the company's drawing office if the problem cannot be resolved at shop floor level. The role of verbal communication in overcoming difficulty in interpreting drawings should never be underestimated. Simpler objects, of course, may be represented just by a verbal or written description.

Children are often loathe to rely entirely on drawing as a means to communicate their design concept. They often make use of verbal description to either compensate for ambiguities in their drawings or to help the teacher correct their work. The former is to be discouraged, as a major objective in the teaching of practical descriptive geometry is to produce drawings which do not need an accompanying verbal or written description. The latter is to be encouraged, as the dialogue between the teacher and a pupil leads to the resolution of some learning difficulty or other.

CHAPTER 5

RESOURCES FOR TEACHING PRACTICAL DESCRIPTIVE GEOMETRY

5.1 INSTRUCTIONAL RESOURCES

5.1.1 INTRODUCTION

Before reviewing research into the various resources that have been used to teach descriptive geometry it is important to remind the reader that nearly all of the research has been carried out with college students. The older student is more likely to have achieved intellectual maturity in the sense that his or her attitude to study will be positive and formal operations will most likely to have been achieved. The school student not only has to endure the emotional upheaval caused by adolescence but also will have difficulty with concepts that require formal operations.

5.1.2 THE TEACHER

The effective teacher compensates for poor resources and improves good resources by a variety of means that has hardly been researched, except at the more general level.
Gagné has provided examples of the different strategies that may be employed to promote learning (2.3.3.6). The examples, which are a select list of the most important, all require, with very few exceptions, supervision of the learner by the teacher.

Although it is not inconceivable that a computer could not perform these functions, at present it is reasonable to consider that only some aspects of the role of the teacher may also be performed by the computer.

The ability of the teacher to decide when and how to promote learning by intervention in a learning task is especially important to the student's progress. But when the students are active on some task the demand for the teacher's attention often leads to queuing. Far from monitoring the progress of each pupil, the teacher's contact time becomes restricted to those pupils who actively seek help. One of the most important functions of learning resources is that they can reduce the demand for the teacher's attention and so contribute to the teacher's effectiveness.

The teacher's ability and attitude to the resources available must determine to what extent such resources will be used and the manner in which they are used. In addition there is no single authority or advisory body in the UK that organises and distributes advice to teachers of practical descriptive geometry. It is most unlikely, therefore, that teachers will in general be aware of research findings on different teaching methods and instructional materials and devices.

Bearing in mind the varying degree to which teachers know of, or appreciate, the resources that are available to them, and the research findings on teaching descriptive geometry and graphical communication, it seems prudent to ensure that any resource meant for the computer is particularly flexible in use.

5.1.3 DRAWING FROM OBJECTS

Real objects provide the teacher with the most logical resource for teaching descriptive geometry, but there are several reasons why the use of real objects to draw from is not widely used. The objects must not be too large as the pupil should not have to contend with the problem of scale as well as measurement. Initially the objects should be simple in form, preferably surfaces should be rectangular in shape. The objects should be of interest to the pupil. The objects should be easily obtainable, if not free, then relatively inexpensive: at the time of writing less than one pound each. Unfortunately it is very difficult to think of objects that have the above attributes. One example that could be used is a small picture frame. Objects that pupils might make, for example, a letter holder could be used as objects to draw. The investigator often asks young pupils to draw objects they have made, even though they had made design drawings before making the object; the reason being that initial drawings are often poorly executed and in addition the design can often change. The new drawings are invariably more accurate and accomplished. Relaxing one or more of the restrictions leads to a wider choice of objects, but it is suprising how complex some objects are on closer inspection. An audio tape cassette might seem to be a possible example but some of the detail is quite intricate, in particular, the drive sprockets. Because of the difficulty of gathering together a collection of suitable objects to draw it is better to resort to the use of models especially with the younger pupil.

A collection of real objects are of course very valuable particularly in discussing design and manufacturing technology. Objects may also be used as examples when discussing geometrical form. A cylindrical surface in itself hardly grips the imagination of the pupil but the cylindrical surface of a camera lens body does, and in addition, the camera lens is itself a section of a spherical surface.

5.1.4 DRAWING THE ENVIRONMENT

In addition to the representation of simple objects and assemblies, descriptive geometry is also applied to large scale structures which include buildings and associated developments from individual houses to whole towns. Projects based on the planned use of space within a school or the home, provides an opportunity to engage the interest of the pupil and also introduces the neccessity to draw to scale and work from maps. Whilst a map is a single view, a plan, the "object" cannot be viewed in the same way as a cassette box or other small object, netherless, it is important to try to develop the pupil's ability to visualise the layout of different parts of the environment. Although studying maps helps pupils develop their understanding of the relationship of the map to the environment, particularly if it is the area where they live, or go to school, there are often problems, because maps or plans are not readily available. Whilst it was not possible within the timescale of this study to develop a computer model of the school, and its local environment, it is feasible.

5.1.5 THREE-DIMENSIONAL MODELS

Three-dimensional models have been in use for some thousands of years to communicate the ideas of the builder and engineer. The descriptive geometry representation for a few centuries. Models are still in use and in certain applications have distinct advantages. GINNS (1968) recommends the use of three-dimensional models right from the start of the design of pipe runs in chemical plant. He suggests that the design of pipe installations using drawing board methods may be less effective because the orthographic representation favours installing pipe runs in planes at right angles, whereas diagonal runs and the use of gentle sweeping curves may be more suitable. BROWN (1972) argues that the use of models saves time in estimating material costs, and improves production by providing shop floor personnel with a visual aid that reduces errors. Models can also be used for forecasting the achievements of a company in advance, and photographs can be taken for use in the press.

SINGER and COULTHURST (1972) use both two- and three-dimensional models in teaching engineering design. They consider that three-dimensional models can be usefully employed in considering layout, ergonomic and aesthetic factors, whilst two-dimensional models are valuable in the design of mechanisms. It is of interest to note that with respect to mechanisms STRANDH (1982, p57) writing about the Swedish inventor, industrialist, and teacher Christopher Polhem (1661-1751) mentions his 'inability to draw even the easiest of diagrams', yet Polhem had a talent for thinking in three dimensions and making simple models to express his design ideas. Polhem created a collection of models, his mechanical alphabet, which he considered to be more valuable than books for teaching engineering. Polhem's 'alphabet' included all the known machine elements at that time. Strandh does not give enough information about Polhem's inability to draw. There are no sketches of mechanisms by Polhem in Strandh's book, but there are a selection of very fine coloured, shaded, and annotated pictorial drawings of some of Polhem's models which were produced especially for the book. It is difficult to comprehend the motions that the models are capable of performing just by studying the illustrations. Perhaps Polhem decided that it just was not sensible to try to communicate ideas involving moving parts by means of drawing.

Mechanisms are a rather advanced topic for practical descriptive geometry but they are relevant to this study as school courses include the study of simple mechanisms, the movement of which pupils find difficult to understand.

Polhem's collection was commisioned by the King of Sweden at considerable expense; to supply the four thousand or so secondary schools in the UK with a set of required mechanical models would likewise constitute a large sum. An alternative means to communicate the function of mechanisms utilising the computer is therefore worth pursuing.

In 1828 the German, Peter Schmid published the first part of his course in drawing: Das Naturzeichnen, which was based on the use of purpose made solid models. The first part of the course was restricted to drawing straight-sided bodies, later parts were devoted to bodies composed of curved and mixed lines, and the application of perspective, and shading (ASHWIN 1980, p.152-153). The most interesting aspect of Schmid's course was the use of labelled drawings which were matched by labelled solids. The solids provided the child with a means to relate the illustrations to the spatial relationships (Appendix 1, fig. 20). In addition, detailed written instructions enabled the child to progress at his or her own pace.

Schmid's course was oriented towards art rather than technical drawing, the increasing importance of vocational and industrial education led to the development of similar courses employing models that were designed to facilitate mechanical and constructional drawing. The most notable being Heimerdinger's "The Elements of Drawing from Solid Objects" (1857), ASHWIN (1981, p. 112). Heimerdinger's course employed an increasingly more complex set of models and stress was given to the development of the conceptual aspect of drawing by directing the student to add hidden detail to his or her views of the models.

One common argument used against the use of models in the above drawing courses was the cost of supplying the models to the pupils; Classes were large, and storage space limited. Similar objections may be made today, even though classes are smaller. In the investigators experience pupils tend to regard the use of models over a long period as being dull, just as they also regard the extensive use of any particular textbook as being boring.

The use of models described above feature large scale structures, mechanisms, or sets of solid models. The difficulties which people have with these categories of object are due to spatial complexity in the case of large scale structures, perceiving the pattern exhibited by the motion of linked parts in the case of mechanisms, and a certain amount of tedium (partly due to the geometric abstractness) associated with solid models.

The child regards much simpler objects as being complicated when represented in the form of orthographic drawings, and as has been pointed out above (4.2.3) it is difficult to supply a class with sets of real objects to study. An alternative is to use models of objects. Small scale models of various interesting objects, eg., cars, boats, and aeroplanes can be purchased quite cheaply. These models can be used in various ways to explore geometric form and the basic notion of the view, both orthographic and pictorial. Detail that is hard to recall from memory, for instance, the appearance of the underneath of a car is readily available for inspection. However, this type of model is still too complex to be used as data for making drawings, except with either the more able pupil or with more experienced classes. It is possible to reduce the complexity of an object but retain its characteristic attributes, its general proportions and shape, but there is no market for such models. The scale models referred to above sell as toys. Larger more detailed, more expensive models not only sell as toys but also as replicas to be placed on display. Simpler models for use as a teaching resource could be manufactured, but unless a definitive market could be established, the costs would preclude purchase by schools.

The problem of communicating how to represent an object, involves discussing the geometric attributes which the object has, and agreeing on the manner in which such attributes must be depicted relative to the views under consideration. Ideally what is needed is a facility to call up a simpler version of an object if the pupil has difficulty with the object under consideration. It is possible to reduce the complexity of a representation of an object in discrete steps and realise each stage by means of models and drawings. These models and associated drawings would provide concrete examples of what is meant by analysing an object into its geometric component parts, and of the reciprocal operation of sythesising an object from simpler forms. Unfortunately teachers are often under pressure to perform all sorts of duties, and the time available for creating such models tends to be slight.

Learning how to perceive geometric features by studying real objects and models is a prerequiste for constructing a drawing, but the more fundamental problem of constructing the two-dimensional image correctly rests on the ability of the pupil to apply the elementary notion of projection. Projection is depicted in various textbooks by glass-like projection planes and thin lines connecting corners of the object to corresponding vertices of the graph which constitute the image of the object on the projection plane. The student reading the textbook has to be able to mentally rotate the depicted spatial structure so as to view the orthographic views. If the student is unable to perform this operation, the effectiveness of the textbook illustrations must inevitably be reduced. (See Appendix 1, fig. 21)

In addition to the facility to supply simpler objects it would therefore, also be necessary, ideally, to supply objects set up within projection planes. These models would utilise thread or fine wires as projection lines to the corresponding drawings of the object on the projection planes. Unfortunately the amount of time and effort that would be needed to make sets of objects and corresponding drawings, and projection plane models, precludes their use.

In addition to the possible purchase of models and objects or their manufacture within the CDT department, there is also the possibility of pupils making models. One of the most important opportunities for reinforcing the relationship between the surfaces of a solid and its form arises out of the activity of making models from developments. Developments of various geometric forms or models of objects can be supplied for the pupil to assemble and these three-dimensional models can be used in a number of ways. Developments for use in teaching solid geometry have been in use for a considerable time. COWLEY (1600) supplied developments partially cut on board to accompany his course. The student was supposed to make the models and use them in conjunction with the exercises. HARRISON and BAXANDALL (1913, p177) also recommend the 'free use of models' by the student. Each of the fundamental relationships between the projection of a spatial form and its projection planes referred to is accompanied by instructions for making a simple model. Unfortunately the models have a limited use in secondary education as they exhibit only the main projection planes and the projection of a line in space, and also an auxiliary plane to obtain that line's true shape. Theoretically this is virtually all that is required, but the student would have to have attained Piaget's formal operations level in order to abstract a spatial line from a three-dimensional concept and relate it, in isolation, to the projection planes

MILLS (1970) advocated the use of models made by students to aid visualisation. 'The student benefits from this type of project because he must become totally involved and actively participate in all phases of a problem-solving activity in which better understanding and visualisation of descriptive geometry is achieved through self-directed study. His interest is stimulated by working on a problem of his own choice, and he is able to express his creativity through construction of a model.' Mills further asserts that the instructor benefits because the Models provide a resource that makes lecturing easier. However, similar reservations apply to Mills' students who were college age as applied to Harrison and Baxandall's students. The models, although strikingly convincing from the photographs, would have little interest for the majority of school students as they consist entirely of lines and planes in space together with projection planes. If similar models could be made of interesting objects then school students would likewise benefit from self-directed model making. This hypothesis is based on the belief that objects of interest support learning by increasing motivation, and by adding differential cues for perception (GAGNÉ'S table 2, in Appendix 1). Unfortunately, it is doubtful whether even college students could make, or even afford to spend the extra amount of time required for the latter type of model.

Modelling from developments is particularly relevant to manufacturing artefacts from sheet material. In order to develop the surfaces of an object it is necessary to draw accurate orthographic views of the object as otherwise the model will be defective. The attention to accuracy helps the student understand the necessity for geometric constructions. However, modelling by drawing surface developments presents difficulty with more complex forms and does not relate to manufacturing artifacts by injection molding, wasting, and extrusion.

Modelling from blocks of material does enable the teacher to relate the design process to the above manufacturing techniques and also offers certain advantages. Solid blocks of material can be shaped by waste removal and by joining pieces together. The systematic removal or addition of material creates a new form which may itself be modified to create a more complex form. Various materials can be used, GIESECKE et al (1949) mention the use not only of conventional materials like clay and wood but also the use of soap bars and potatoes. Modern technology adds materials such as high density foam (HDF) to the list of possible resources for modelling. HDF is a type of polystyrene foam which is so dense as to enable a very smooth finish to be obtained similar to plaster but without plaster's brittleness. HDF is easy to cut and shape and is available in much larger pieces than soap. Students can design directly with HDF without having to grapple with the constructional geometry that is necessary with modelling by creating surface developments. Such models may be used to help the student with drawing as well as contributing to the student's design skills.

LINES (1935, p1) considered that in addition to the use of student made models it was most instructive to use the classroom as a model. 'The larger the model the more instructive it can be, especially if the student is free to walk about inside it. It should be born in mind that our sense of the solidity of things depends primarily not on their appearance, but on our ability to handle them, and to move about in relation to them.' LEVENS (1962) introduced the notion of the 'thought model method' in an experiment whereby a teaching technique that he had used for many years was presented to other teachers by means of six films. The method is based on the belief that students are more likely to understand orthogonal projection if the teacher first uses his body to emphasise the spatial concepts that are involved. The teacher primarily uses his hands to trace out points lines and planes to support a verbal interpretation of the problem to be solved before carrying out a solution on the blackboard. The investigator has also used this method and finds that his pupils are more attentive. The method can be used to introduce an element of drama into the lesson which can be usefully employed. For example, imaginary Karate or Kendo movements can be used to communicate the difference between the major sectional views and the nature of the sectional view itself.

Although a lot of time can be spent on making models for display and demonstration purposes, with care, such models last many years. But models have a limited use in secondary education because of the difficulty of making objects that are intrinsically interesting to the students. Most students, it must be remembered, will not have achieved Piaget's formal operations, or from Bryant's theory they will need framework cues to relate spatial relations exhibited by the object to their own sense of direction. These cues are more likely to be perceived when the objects under consideration are recognizable and interesting.

5.1.6 PHOTOGRAPHY

In addition to the use of real objects and models, teachers may also utilise photography. Photographs of an object can be produced considerably cheaper than models. Using the xerographic process, copies may be made from printed photographic material, albeit with some loss of quality. This means that subject to copyright restrictions teachers may make use of a vast amount of pictorial material with very little effort on their part. This photographic material may be combined with drawings and text to create instructional material to suit the needs of the individual teacher.

Still photography is a two-dimensional medium and as such each photograph must be taken from a specific viewpoint, whereas an object or model can be viewed from different directions. Cine and video cameras enable movement to be recorded and also enable an object to be viewed from a variety of positions these attributes place film closer to handling objects than photographs. When an object is handled in addition to visual sensations we are also sensing the object's form by means of its tactile qualities. We thus have considerable freedom to inspect the object. Whilst film removes our freedom to handle the object it also does not allow the individual to choose a viewpoint, except when the film is made by that individual. Cine film is expensive compared with videotape and cine has to be sent for processing before it can be viewed. Video although of a lower quality than cine can be used with considerable freedom and could be used by both teachers and pupils to study the relationship between the objects appearance from different viewpoints within the time scale of the lesson.

Photography is a mechanical graphical reproduction of a region that lies in front of a camera lens, as such it has a high degree of credibility compared to drawing. The creation of a drawing is subject to human error. If the person viewing the drawing is puzzled by some aspect of the object which has been drawn he or she may quite rightly have some doubt as to the accuracy of the drawing, whereas the same object which has been photographed must be considered somewhat differently. The photograph 'cannot lie' it is a mechanical means of representation. The photograph records only what does exist, whether as an image of an object,or an image of a model of an object; subject to the type of lens employed, and its quality. Whereas the drawing may also record a design which could exist but also because of errors could not exist.

The photograph captures the attributes of colour and tonal gradation including the surface quality of an object. These attributes are often absent from drawings, particularly technical drawings. For the very good reason that they are superfluous to the function of the technical drawing, which is to describe in terms of engineering graphics and descriptive geometry the form and construction of some artifact or structure. But it is not wise to remove those secondary attributes of colour and solidity too soon in the study of technical graphics. It is reasonable to hypothesise that when the teacher is introducing some new geometric notions it would be desirable to use objects, models, and photographs and film as these resources are more concrete than line drawings.

The manner in which educational visual resources are used outside the classroom to help and inform varies according to the target audience. The best examples of the use of visual resources are more likely to be found outside the classroom as considerably more time and effort may be devoted to them. For example, car workshop manuals provide an excellent example of how to use both drawings and photographs to advantage. The

Haynes series of car workshop manuals is an interesting example of the extensive use of photographs rather than drawings as an aid to understanding. Open University programmes on television provide interesting material for studying the use of models as visual aids.

The workshop manual is designed to function as self instruction material because the user has little or no access to a teacher or instructor. The quality of the visual material and text needs to be of a very high order and to a large extent such material is a poor substitute for the personal interaction that becomes possible between a student and a teacher. The Open University programme also has to compensate for the removal of personal contact that is unavoidable with distance learning. The programme attempts to anticipate difficulties that the student is likely to have and considerable effort is spent on devising various visual aids.

The classroom teacher does not have the time or the money to devote to developing first class visual aids or the money to buy such aids. Greater reliance is thus placed on the teacher and if students have difficulty it is up to the teacher to explain, to elicit questions, to use examples and to devise or use whatever visual aids are available.

Photographs have been in use in technical graphics textbooks since the end of the Second World War primarily to illustrate engineering processes or to depict some item of equipment for drawing or device used as a visual aid. EARLE (1972) introduced the extensive use of drawings and particularly photographs of interesting objects in a book meant for college students. The book was evidently a success as Earle used the same strategy in a later work (1977) to an even greater extent. The photographs are used to improve the student's perception of the geometric form of the subject matter, which is more explicitly shown in the drawings. It is important to note that the subject matter has been chosen to capture the imagination of the student.

Earle's determined attempt to reinforce the student's commitment to studying engineering design and graphics by the use of photographs and drawings almost exclusively dedicated to objects that are interesting, eg space capsules, aircraft, boats, astronomical telescopes, cars, trucks, sporting equipment, locomotives, modern buildings and assemblies taken from such objects has hardly been emulated in textbooks for the school pupil either in the UK or the USA. It is true that photographs are being used much more in school textbooks than was the case twenty years ago, but unfortunately, the subject matter of the photographs often seems to be of little interest to the pupil.

Photographs are also used extensively in contemporary examination papers. Examination questions with accompanying photographs get reprinted in textbooks and as a consequence it is difficult to determine whether the photographic content is not as interesting as it might be, because much of it has been derived from examination material or because of some other reason.

Instructional material and examination questions can be analysed into a basic problem to solve structure that consists of: given this information, do some task. For example, given a photograph of an object and a partly completed view of that object, complete the view. Rarely is photography used except as a means to supply supplementary information or to stimulate interest, but photography could be used to explore the relationship between the viewpoint and the object in a variety of ways.

Whilst photographs convey a vivid image of an object, the geometric form of an object is determined by perceiving surfaces and associated features: edges, contours, and corners. These features are recorded relatively indistinctly, unless special precautions are taken. Most of the photographic material used in technical literature has been very carefully illuminated, photographed with a large format camera and has then been subject to retouching. An alternative method of improving photographs that are meant to be used as pedagogic material is to improve those attributes of the object which need to be distinct before the photo is taken, eg the edges of the object can be accentuated with ink or special models could be made that have distinctive features.

The investigator has used paper models that have all edges inked in before they are folded and glued to make a model. These models have very distinct edges and can be photographed in various ways. The student usually makes the models and can compare the models to the photographs and make drawings using both. The pupils usually enjoy this sort of work as it involves a number of skills and the varied activities stimulate interest, particularly as the models are of buildings. Project work making more complex objects particularly those involving combinations of curved and flat surfaces present much greater amounts of difficulty and there just is not enough time in the technical graphics examination courses to carry out such work, except to a very limited extent. This is a pity as very few pupils, in the investigator's experience, appear to develop a good understanding of the more complex three-dimensional solids and spatial structures.

It is very difficult to explore the relationship between the viewpoint and the object by means of a series of drawn perspective views, as the perspective views need to be very carefully constructed. Apart from the amount of time required there is also the practical difficulty of drawing the necessary construction lines when the station point is a great distance from the object. But a necessity if the gradual reduction in the perspective effect with increasing distance from the object is to be communicated. Instead of drawings, a camera could be used to produce images of an interesting object from various viewpoints. Using lenses of varying focal length the effect of perspective could be explored at a fraction of the cost of drawings.

Unfortunately, the use of photography to explore the geometry of representation has been neglected, at least in as much as there is hardly any research in the area. McCAGE (1970) utilised photography to produce slides which were used in conjunction with models to help students understand what practical descriptive geometry is used for. An approach which he found improved the students understanding of the subject. But the slides were designed to shed light on the industrial applications of the geometry rather than on the fundamental geometry itself. There is also very little use of photography as a medium in textbooks, except as mentioned above and no reference to articles in journals by teachers whether of technical graphics, maths, or art were found.

Just because there is no published material does not mean that there is no activity in the field. The investigator is using photographs to help students understand perspective drawing, and within the school other CDT and art teachers are also using photographs, but even within the school it is difficult to gain anything more than a superficial understanding of what others are doing. The problem is that there is little motivation for teachers to write about their possibly novel use of photography or any other medium, and no authority whose brief it is to visit schools and prepare reports on innovation in the classroom.

The investigator's photographic material consists largely of cuttings from magazines rather than photographs that have been taken for the express purpose of exploring perspective. This is because such work needs careful planning to be successful. One of the problems is the difficulty of editing unwanted content from the scene to be photographed. Ideally what is required is a purpose-built set to photograph from a selection of key positions. This set would have to be life-size as the perspective effect is different in a model. Models can be made; there is a fine collection in the Science Museum, but such models are unique to a given viewpoint and extraordinarily difficult to make. It is feasible for such a life-size set to be synthesised by the computer and perspective drawings generated at a fraction of the cost.

The student is obliged to accept that a drawing is correctly produced; if it looks slightly odd, he or she may challenge or worse still doubt that the drawing has been produced correctly. Photography being a mechanical means of representation is arguably less likely to arouse doubt, and may even be of greater interest. Where there are distortions the cause can usually be readily detected as being possibly due to the use of a wide angle lens or other piece of equipment. The objects for a series of photographic representations could be varied in complexity, by differences in form, colour and material. For instance, a white painted object with edges accentuated in black photographed against a white background provides a link between the real three-dimensional world and the two-dimensional world of the line drawing. Rather suprisingly this sort of photographic project has not been undertaken for the benefit of the teaching profession. STEINHAUS (1950) has extensively employed photographic images as a means to illustrate topics from many areas of mathematics, unfortunately, although solid geometry is well represented, he has ignored the descriptive geometry area. GODDIJN (1980) has used photographs for exploring the perspective effect but has not advanced beyond a very elementary level.

5.1.7 DRAWINGS

5.1.7.1 INTRODUCTION

A primary aim of those courses which have practical descriptive geometry as a major component, is to to learn how to construct technical drawings and so contribute to the development of the skills and knowledge required to solve spatial problems associated with manufacturing technology. It is therefore obvious that the major resource for teachers is drawing, and it is important to establish what teachers use drawings for, what graphic material is available, and what teachers might like to do with types of illustration that are difficult to draw and so are unavailable, bearing in mind the possibility that they could be produced by computer.

5.1.7.2 THE HMI PAPER

The HMI paper mentioned above (section 1.1.3) is the only document that reviews technical drawing type courses in England. Although published in 1984 the Inspectors made their visits during the period 1980-81. They visited 75 secondary schools, and although this only represents less than 2 per cent of schools the sample was regarded as representative.

Much of the drawing carried out by students in a majority of the schools visited by the HMI involved copying exercises using textbooks. The result being that discussion was generally seen as unecessary and few opportunities were made for pupils to talk about their work other than to ask questions of fact or for advice on the next step of the exercise. Consequently the students could give little more than a brief description of the current exercise.

However, in a few schools teachers were introducing new approaches, efforts were made to ensure that students had opportunities to use or incorporate their own ideas in at least some of the work undertaken. Students adopted a variety of methods of communication including freehand sketching, models, and working drawings which were augmented by notes. Drawings were thus used in a more meaningful way. Teachers supplemented textbook illustration with their own drawings which comprised some or all of the following: blackboard drawings, overhead projector (OHP) drawings, overlays, slides, and worksheets. In addition to drawings teachers also used physical examples, models and photographs. The HMI also noted that some students had difficulty communicating their ideas, even though they had a clear idea of what they wished to achieve. Clearly it is more difficult to offer a course which enables students to engage in creative work and still ensure that the syllabus is covered, this particularly applies to Technical Drawing. Graphical Communication was intended to broaden the scope of schoolwork and it was hoped that this would encourage teachers to develop a more design-based course. According to the HMI this has only been partly sucessful: 'they appear to have had little effect on the syllabuses followed and have not resulted in a reappraisal of the types of learning experiences that the subject has to offer.' (ibid, p8) Since the HMI paper was printed there have been two major changes: the introduction of GCSE and of the new syllabus CDT: Design and Communication. It remains to be seen whether the desired changes will provide a better environment for improvements to take place.

5.1.7.3 DAVIES

The problem is only partly due to syllabuses, there is no reason why a creative course could not be developed based on the old technical drawing syllabus. According to DAVIES (1977) teachers quite rightly see as one aim of secondary education to train pupils for future employment and this view might lead to an imbalance between drafting and knowledge. Many craft teachers believe that before a student can comprehend a drawing he or she must be trained in drafting. 'The long periods of drawing production exercises inflicted on students by many teachers seems to substantiate this ill-informed philosophy'. Davies goes on to argue that a student can learn to interpret drawings without having to endure the tedium of carrying out endless engineering drawing exercises.

Even when the teacher does see the value of developing more generalised study skills and aims to develop the pupil's creative ability there is the task of developing materials and assisting pupils often on a one to one basis.

The difficulty of developing opportunities for creative work is largely due to the extra time and effort required to prepare supporting illustration for teaching. Since the computer can produce drawings as well as screen images it is worthwhile exploring the various possibilities that teachers may use, or would like to use but are reluctant to do so because of the time and difficulties that creating such drawings present.

5.1.7.4 TYPES OF DRAWING AND THEIR USE

Drawings can be classified according to whether they are a particular method of illustration, eg orthographic, isometric, perspective, etc. These methods may be used in a variety of ways. For example, several perspective views could be constructed to be used for establishing an understanding of the relationship between perspective and orthographic views. To take another example, a set of isometric drawings and a perspective drawing may be required to enable the student to understand the eight possible viewpoints for isometric drawing. Either of these objectives would involve the teacher in a considerable amount of work. Both of the above examples have been selected because it is difficult to find similar material in textbooks (both UK and US).

Pupils need to be taught how to select an appropriate method of illustration to produce satisfactory work and they need to learn how to construct the various types of view. Although textbooks include sections on various methods, they leave much to be desired. It is not often apparent to pupils that a particular method is more appropriate than another. It is desirable to collect a folio of examples using commercially produced advertising and information material, but although such material may be excellent for showing pupils an appropriate or an inappropriate method they do not provide much opportunity to develop an ability to construct a particular method of illustration.

It is time-consuming to patiently go through a topic with a group trying to ensure that all the pupils do understand the topic. The more able pupil tends to become impatient and the pupil who has difficulty concentrating for more than five minutes or so tends to daydream. To minimise the amount of verbal explanation, topics could be accompanied by more drawings selected to clarify the character of the various methods.

It is not only essential for the student to learn what method of illustration is best suited for a particular application but also to make sure that the student can employ the selected drawing method. It seems sensible to separate these two objectives as otherwise the student is likely to be thinking about the constructional difficulties whilst the teacher is attempting to communicate that a particular method is more appropriate than another.

One possibility is to provide different methods of illustration for exactly the same object. This would enable the students to compare the methods and only the methods, as they would not need to discriminate between the objects depicted as well. This particular strategy is not used in textbooks possibly because of the amount of extra illustration required.

The automatic computer-generated production of methods of illustration would enable sets of views of different objects to be produced. The pupil would benefit by having a large number of concrete examples of the different methods: similar features could be more easily detected and hence assist in developing the pupil's ability to generalise. See Appendix 2, figures 1-3.

5.1.7.5 DRAWING EXERCISES

Exercises from textbooks tend to be limited in their application: often a more demanding exercise is required or conversely something simpler. The teacher is free to design additional exercises. These may be modifications of specific exercises from the teacher's textbook or they may be new exercises. The production of the latter require designer's skills: ideas, and usually some draughting. Given the former it is the latter that often form a stumbling block as producing neat drawings can be rather time-consuming, even when all that is required is to draw an isometric view on grid paper.

For example, a popular worksheet that the investigator was using consisted of an isometric view of a spacecraft accompanied by two orthographic views (plan and elevation). Both views were drawn on isometric grid and square grid paper respectively. The pupil had to modify the craft by possible additions and alterations. Some pupils were reluctant to modify the craft and to encourage them a kit of cut-out parts was developed. These parts were drawn on isometric grid paper and consisted of a selection of geometric forms that could be placed on their basic drawing so as to see what additions could be made. Several alternative wing and engine parts were also supplied. These parts were well received not only by the 'reluctant' designers but also by the others. But the reluctance on the part of some pupils persisted.

It was further considered that they had difficulty with the fundamental problem of visualising the form of the craft and this expressed itself in a reluctance to draw. The addition of another isometric view showing a view from the back of the craft improved the effectiveness of the exercise, but since the orthographic views should be sufficent it was decided to produce two perspective views of the craft, these views would enable the pupil to gain a more vivid impression of the craft but would also force the pupil to scrutinise the orthographic views to gain precise information. The new sheet was more effective in stimulating the reluctant designer. Generally pupils asked for more help, an indication that to some extent they had tended to copy the isometric view before. Computer programs were used to generate the perspective views and without such a facility it would not have been feasible to produce the views, especially as it was not certain that the modified sheet would be more effective. The substitution of the perspective views for the isometric views was a small variation but worthwhile as the changes brought about quite distinct improvements in pupil's behaviour. See Appendix 2, figures 13-15.

It could be argued that it is not necessary to have a facility to generate perspective views as descriptive geometry is based on the concept of the orthographic view. Descriptive geometry drawing type courses in secondary schools in the UK, and probably elsewhere, have as an essential component descriptive geometry, although syllabuses prefer to use the terms solid geometry and orthographic projection. Such courses include technical graphics, which might include building construction drawing as well as mechanical engineering drawing and information graphics.

The Graphical Communication syllabus and GCSE CDT: Design and Communication syllabus only requires pupils to be capable of drawing simple estimated two-point perspective views and it would be reasonable for teachers to infer that such drawings do not require a thorough understanding of perspective projection. This seems quite reasonable as it would be relatively easy to design a two-year examination course which dealt only with perspective drawing and such a course would have to either include the study and construction of orthographic views or assume prior knowledge on the part of the student. (HOLLIS, 1955, P12)

On reflection it does not seem there is much to be said for teaching pupils to draw an estimated two-point perspective view without attempting to provide them with some understanding of perspective drawing in general. Without such understanding even quite able pupils make the most simple mistakes. Whilst acknowledging that excellent work can be carried out by means of investigations using photographs, the facility to generate accurate perspective views using a computer would enable greater control over the design of instructional materials.

5.1.7.6 DESCRIPTIVE GEOMETRY AND PERSPECTIVE

It is not only in the study of perspective that the facility to generate perspective views is valuable as orthographic views are a type of perspective view. Although they are not usually regarded as such. (see section 3.3.1 above)

Descriptive geometry is commonly studied separately from perspective drawing. This is because descriptive geometry is the essential theory for engineering graphics and perspective is only important in relation to architectural graphics and the presentation of design and technology work. An advanced course would employ descriptive geometry for topics which would include the study of all types of geometric surfaces and forms, and the construction of perspective views including shades and shadows (PAL,1966).

Since the textbooks do not in the main, attempt to establish the conditions that give rise to the several drawing types by reference to projective drawing in general, and because it is relevant to this thesis, a synthesis of the various drawing types is set out below.

The factor that sets the orthographic view apart is the position of the viewpoint at an infinite distance from the picture plane, thus obviating the necessity to find vanishing points (all parallel lines will remain parallel). Confusion arises because it is possible to discover special views depending on the line of sight. By exploring all the possible directions from which an object can be viewed it is possible to identify each specific type of view and consider how, if at all, it may vary.

Considering the primary directions first, that is those directions which relate to width, height, and depth; there is a direction relative to any given object whereby one of the dimensions of the object disappears, eg in a front or back view the depth dimension is not visible, in the top or underneath view the height dimension disappears, and in a left or right view the width dimension becomes indeterminate. These restrictions give rise to six main **orthographic views** if the viewpoint is regarded as being at an infinite distance away.

Keeping the viewpoint at infinity and moving around the object it is possible to achieve eight positions whereby the dimensions of the object are foreshortened by exactly the same amount. These eight views are termed **isometric views.**

Similarly, directions can be taken whereby only two dimensions of the three are foreshortened equally. Since the third dimension may vary there must be an indeterminate number of such **dimetric views** but they have a special relationship to each other in that the angle of rotation to the equal axes corresponding to the dimensions remains constant (45 degrees).

Finally, there is the general case whereby all three axes are foreshortened. This type of view is called a **trimetric view.**

It is further possible to vary the position of the object relative to the projection plane in order to yield **oblique** type views. Some confusion has entered here as there are two types of oblique view corresponding to whether the view is considered to be projected obliquely onto a vertical plane or onto a horizontal plane. The latter is termed a **planometric** view because such views can be drawn directly from a rotated plan. The former has no special name and is usually termed an **oblique view** or **cabinet oblique** as this type of view is common in the furniture trade. The view can be drawn directly from a frontal elevation. In both cases only one dimension will be foreshortened.

Relaxation of the limitation to hold the viewpoint at infinity generates views that have the perspective effect of converging parallels to a greater or lesser extent depending on the distance of the object from the viewpoint. Some of the infinite number of such perspective views have certain characteristics which enble them to be labelled **one point, two point** or **three point perspective.** These terms actually refer to certain conditions whereby some sets of parallel lines, those that lie parallel to each of the three axes that can be associated with three-dimensional objects, either do or do not converge toward a vanishing point. This might seem to be stating the obvious but leads to the notion that if no sets of lines converge then an orthographic view is generated.

In practice the types of view that are peculiar to certain restrictions are defined as drawing methods that can be constructed using rules and as such are rarely regarded as belonging to a family. These rules are invaluable in providing students with the means to construct various views but tend to obscure a fundamental truth that is that all views are determined by just three factors: the position of the eye, the distance to the object under observation, and the location of the projective plane (in the case of oblique views).

5.1.7.7 SYLLABUSES AND COURSES

Although technical graphics syllabuses aim to have as a primary objective the development of an ability to visualise and understand spatial relationships, they tend to limit their objectives in the graphical area to performance objectives eg '..to develop an understanding of graphics for representing design concepts' and 'To develop order and accuracy in visual representation.' (London Univ Graph. Comm. Syll 1982/3). The GCSE CDT: Graphic Communication syllabus 1987 is essentially the same. The GCSE CDT: Design and communication syllabus does include as one of its aims 'to promote the development of curiosity, enquiry, initiative, ingenuity, resourcefulness and discrimination' but this is a rather general aim. No mention is made in any of these syllabuses that students should be given the opportunity to develop an understanding of the processess of graphic representation in terms of descriptive geometry and their own perception of the visual world.

It is hardly suprising that students may only manage to become competent in drafting and fail to develop their ability to visualise and understand spatial relationships if they do not have an understanding of how a view of an object can be created by applying science rather than routine.

Students must be aware that there are other possible views as they are quite likely to see examples in magazines and books, and perhaps be disturbed that the illustration does not seem to be like the teacher's isometric drawings.

Students learn to apply various methods of illustration but except for the efforts of the isolated individual teacher it is unlikely that they are taught directly to discriminate between all categories of view. This could be accomplished by sorting cards depicting objects that have been drawn using the different methods. Collections of drawings cut out of magazines or photocopied from books may be used but as has been pointed out above (section 5.1.7.4) the computer-generation of illustration would be better as a single object could be drawn using all methods. The facility for a student to decide on the position from which an object can be viewed and create a drawing also becomes possible with the computer. At present students must discriminate between different methods in order to apply those methods effectively but they can do this because they have created several examples and learnt to associate the appropriate label with the type of drawing method. The particular term eg isometric has no meaning to the student, although the student is quite capable of observing that an isometric drawing looks larger than life and in certain applications looks odd. In future it will be possible to provide students with the means to explore these perceptions and gain a better understanding of the relationship of the viewpoint to the object.

In the meantime it seems sensible to try to ensure that pupils are aware that there are other drawing methods and that these correspond to different viewpoints, although they will not be examined in them. It would be necessary to state this more strongly as an objective in syllabuses than it is at present.

It should be noted that students are not likely to learn more about perspective and other types of view in their art studies as there is no requirement to be able to construct perspective drawings from first principles in art courses, whether school courses to O and A level GCE or degree level courses in Fine Art. Art syllabuses in general place greater emphasis on expressive work, and perspective drawing is only studied in relation to drawing and painting from observation.

5.2 CONCLUSION

Often a teacher's instructional material could be improved by varying the scale of the drawing; adding or removing a grid, colours and or shading; changing the type of view, the viewpoint, or supplying additional views. But many of these options usually involve considerable work. Accurate construction of perspective views are particularly time consuming.

Although there is little evidence to support the use of stereoscopic drawings of the anaglyph type, (HATLEY, 1969) teachers might wish to use the technique but are deterred by the difficulties. The design and production of animated film for didactic purposes using hand produced drawings is also uneconomic. This is particularly unfortunate because the medium offers the operations of movement around an object as well as rotation of an object. These dynamic operations are powerful aids to visualising spatial configurations (LIPSCOMB, 1981).

Although any drawing can, in theory, be produced by hand the absence of a widespread use of drawings to commmunicate spatial concepts lends weight to the assertion that it is too expensive to produce illustration. The alternative explanation, that it is unnecessary to produce such illustration is hardly worth consideration.

Perhaps with the development of computer-generated illustration it will become possible to provide pupils with a better understanding of the essential unity of drawing as the labour of producing any particular view is managed by the computer program.

CHAPTER 6

COMPUTER GRAPHICS

6.1 COMPUTERS AND TECHNICAL GRAPHICS

There have been very few research projects which use the computer to help teach descriptive geometry.

ZSOMBOR-MURRAY (1978) reports on the development of a computer-aided instruction language which is used to help teach descriptive geometry. The development is of little interest as the program can only deal with a limited number of spatial lines and is difficult to use.

GROOM (1982) found that college students following an introductory course in engineering graphics using a combination of traditional methods and computer graphics required far less time to complete their assignments than a similar group of students who were taught by traditional methods. As the programs employed were virtually two-dimensional drafting routines, the students were unable to view the objects under consideration, manipulate them using spatial operations, or design objects.

LIPSCOMB (1981) investigated the means by which the perception of depth in two-dimensional display could be enhanced. These included rotation, intensity modulation, and stereo. Lipsomb's research was designed to be of utility in the field of biochemistry, in particular the study of molecular spatial structures. Nethertheless, some of his findings have relevance because of his work on depth perception and close attention to human factors in the design of the devices to control the motion of the image and other techniques (the 3-D joystick).

Lipscomb found that depth perception could be improved by several techniques: rocking or oscillating of the structure about an axis, smooth rotation both continous and through 90 degrees sweeps, stereo, and intensity modulation. The latter enables a semi-transparent curtain to be moved through the structure thus reproducing a sort of aerial perspective effect. He also observed that users preferred to increase the angle of parallax for stereo, and that stereo could hinder the manipulation of the object. Several other findings are relevant but too complex to mention here, notably orthogonality of functions.

The lack of activity in the field of applying computers to spatial education must ultimately be due to the lack of suitable software rather than lack of interest. Of the several citations that Groom makes there is repeated reference to having to teach programming in engineering courses which utilised computer graphics. This requirement would have deterred many would be users.

In the UK John Vince (VINCE, 1975) developed a language which he called PICASO which was suitable for graphic designers. The author has taken part in the development of the language as a student at Middlesex Polytechnic and it was this experience, rather than the close proximity of the three sites of the school to the polytechnic, that provided the future opportunity to utilise the computer.

6.2 THE PICASO SYSTEM AND PROGRAMMING

6.2.1 THE PICASO SYSTEM

PICASO stands for PIcture Computer Algorithms Subroutine Orientated. It consists of an integrated system of procedures that are sensitive to a common data structure to handle two- and three-dimensional graphic structures.

PICASO was developed primarily to meet the needs of artists and graphic designers. It was extended to also provide facilities for engineering and mathematics. In the 1970's there were very few computer languages or programs which could be used for creating two-dimensional and three-dimensional graphics. (VINCE 1975, p.4-7)

In the 1980's there exists a considerable amount of software which could be used for creative and technical graphics but apart from PICASO most of this material is either written to produce two-dimensional graphics or is dedicated to solid modelling. The latter usually requires a special graphics tablet and an expensive graphics terminal or dedicated computer. Market forces have channeled development into solid modellers for engineering or two-dimensional graphics packages for producing business graphics. Recent developments also include text and typesetting. Whilst the solid modellers could be used to produce illustration for technical graphics, with a price tag of £30,000 or more, such machines are out of the reach of schools and limited in their applications. PICASO incorporates both two- and three-dimensional facilities and does not depend on the use of a specialised workstation.

The PICASO System is written in FORTRAN IV a computer language which is widely used in technical and educational institutions ZWASS (1981, P.123). FORTRAN stands for: FORmula TRANSlation because it was designed to be used for technical applications rather than business.

At present the computer language BASIC is widely used in schools. BASIC stands for: Beginners All-purpose Symbolic Instruction Code. The BASIC language is supplied with the microcomputer in a ROM (Read only Memory). Other languages can be purchased for microcomputers but they use up a portion of the computer's RAM (Random Access Memory) which leaves less room for the user's program. BASIC is a rather slow language to use for graphics as each instruction to the computer must be interpreted into machine code. This becomes wasteful when instructions are repeated, especially as calculations for graphics, particularly three-dimensional graphics, require extensive use of trigonometric functions. Another disadvantage is that many versions of the BASIC language do not allow the use of independent procedures, and in addition BASIC is not easily transported from one machine to another.

6.2.2 FORTRAN PROGRAMMING AND PICASO

FORTRAN programmers may make use of special-purpose programs units called subroutines or functions. The programmer writes an instruction to make use of a particular subroutine or function by referring to its name: eg. CALL CUBE(A,6.0). This instruction would create a route in the program to a PICASO subroutine called CUBE which generates a cube as a three-dimensional data structure and stores it in part of the computer's memory referred to in this instance as "A". The FORTRAN programmer can also write his or her own subroutines or functions. A typical FORTRAN program consists of CALL statements to procedures which may be the work of the programmer or may be someone else's work stored in a library area of the computer's memory. This facility enables quite modest programmers to write programs which carry out very complex calculations and operations. It is to be noted that a CALLed subroutine or function may itself CALL other procedures, and these procedures may in turn call other routines.

Whilst the engineer or scientist is quite likely to learn FORTRAN programming as part of their specialist education the graphic designer, artist, craft teacher, and book illustrator not only does not learn programming, but is quite likely to be not well disposed to learning programming VINCE (1975 p.10). But whatever the education of the user he or she does not want to reinvent the wheel.

Although PICASO is a language in its own right it is written in FORTRAN IV and as such provides a considerable scope for the user. The subject of this study is an application of PICASO to problems that would be difficult and tedious to accomplish by a PICASO programmer, and virtually impossible to accomplish in FORTRAN.

6.2.3 PICASO REFERENCE MATERIAL

To provide the reader with more detail about the PICASO SYSTEM its operation and structure a booklet: 'PICASO' is bound in with the other reference material at the end of Appendix 1.

6.3 THREE-DIMENSIONAL COMPUTER GRAPHICS

6.3.1 INTRODUCTION

The PICASO SYSTEM has a number of commands which must be used to display or draw an image of a three-dimensional structure. These commands correspond to the geometric concepts which are required to construct by hand a similar image. Although the user does not have to think about the computation which must be carried out by the computer it is essential to establish the relationship between the viewing position, the projection plane, and the object. These concepts need to be discussed as they determine certain essential requirements for the design of programs and preparation of data.

When a person draws an object onto paper, decisions are made, judgements employed, preliminary sketches may be referred to, photographs or objects might be scrutinised, measurements taken, adjustments made. The resulting drawing may be technically correct or it may exhibit errors which are incompatible to the method of illustration apparently being used. The organisation and execution of the procedures which lead to the eventual completion of the drawing is somewhat taken for granted.

The production of three-dimensional images using computers is by contrast perfectly clear, at least to those who can follow the mathematics and the program's logic. Even to the non-numerate, the fundamental concepts are fairly easy to grasp. Take first the viewing position, station point, or position of the eye. The direction of sight which will determine the projective geometry of the image of the object must be considered as a direction and mathematically data which determines a line is required. One end of the line will be located where the eye is stationed, the other end needs to be located towards the object under consideration. To determine this data the eye and the object have to be located within a frame of reference this must be either a so-called Cartesian XYZ coordinate set up or the analogous spherical coordinate system. The former is usually more convenient.

The object may be centred at the origin of the XYZ set up, which is usually the default position or elsewhere. The eye must of course be directed towards the object. The PICASO command to set up the eye position is: CALL EYE(XE,YE,ZE,XP,YP,ZP). The expression in the parentheses consists of three variables for the eye's station point and three for the point under observation thus determining the line of sight. The picture plane is set up automatically perpendicular to the line of sight, a feature which is usually absent from drawings produced by hand which must therefore be somewhat inaccurate if the line of sight is not horizontal. PICASO has a command to set up an eye to generate orthographic views.

The viewing area can be set by a CALL FRAME command. FRAME is set relative to the projection of the origin on the picture plane. Any parts of the projection outside the frame will be automatically suppressed.

6.3.2 OBJECT DATA

The object or spatial structure under observation needs to be defined mathematically. PICASO contains a library of both two- and three-dimensional shapes and forms. Two-dimensional geometric forms are referred to as 'shapes' and three-dimensional forms are referred to as 'objects' in the PICASO language. Both shapes and objects can be generated by CALLing into operation library subroutines. In addition a three-dimensional design may be entered surface by surface. Input is by keyboard or other device into a file of a proscribed format.

The manner in which PICASO determines whether a surface is visible or not requires that a surface be defined by entering a set of points which are equivalent to a clockwise path around the corners of the surface. Thus for a triangular surface each of the three corners would need to be determined by the X, Y, and Z coordinates of the point which represents the corner or vertex in the conceptual XYZ coordinate set up. Any convenient vertex may be chosen as the first point but to complete a circuit the last point will be indentical to the first. A marker in the data acts as a flag to determine the end of a circuit or contour. A complete object eg a triangular pyramid will need four contours corresponding to its four surfaces. Another marker determines the end of the data for a discrete object.

Common forms can be conveniently generated by CALLs to the PICASO Object Library routines. In addition the PICASO subroutines COPY and JOIN enable duplication of objects and joining of two or more objects to form more complex objects thus enabling three-dimensional designs to be realised. The facility to generate geometric forms is invaluable as otherwise the only methods available are using a digitiser to read data from a drawing, or entering data directly, or from a data file. For example, a cube generated requires merely the length of one side as data, whereas, entered surface by surface it would be necessary to enter 30 sets of points, ie., 90 numbers plus markers.

However, if component parts of a design are generated by using the PICASO Object Library, it is necessary to take account of the manner in which the geometric form representing the part is generated, as typically a form is generated centred on the coordinate origin or with one point located at the origin. This means that the generated form will need to be moved to the correct position by making use of a PICASO routine to relocate the form in the desired position. There are two geometric operations which might need to be used: translation and rotation, possibly both might be required.

6.3.3 DRAWINGS AND DATA

Although it is possible for a user familiar with PICASO to visualise simple three-dimensional designs, and analyse them into a set of geometric forms, equivalent to objects that can be generated by PICASO, and synthesise these PICASO type objects into a model, some form of drawing is essential.

The type of information that needs to be extracted from a drawing in order to use PICASO may be placed in three categories:

1. the number and type of geometric forms which the design could be synthesised from,
2. the location of the various forms in relation to the XYZ coordinate axes,
3. the XYZ coordinates of surfaces that can not be generated by PICASO library subroutines.

Although it is possible to use a pictorial method of drawing, to provide the source for the data (see Appendix 4, fig. 26.) it is better to prepare orthographic views. The number of views required depends on the complexity of the design concept. The views need to be set up relative to an XYZ coordinate set up. PICASO uses a right handed XYZ axial system that relates directly to the international mathematical convention for XY coordinates. The X- axis is the horizontal axis with its positive sense being directed towards the right-hand side, dimensions that are aligned with the X axis are referred to as widths. The Y-axis is vertical its positive sense being upwards dimensions parallel to the Y-axis are referred to as heights. The Z-axis corresponds to depth and its positive sense comes forward towards the viewer.

Each orthographic view needs to be labelled with the appropriate axes, the front view will be labelled with the X- and Y-axes, the Z-axis being reduced to a point. See Appendix 4, fig. 1. for an example of labelling. Note that orthographic views are easier to understand if they are drawn either in 1st or 3rd angle projection.

Once the axes are labelled the design needs to be analysed and divided into discrete geometric solids. Each part should be identified, preferably with a name or letter rather than a number as the latter can cause confusion, bearing in mind that a substantial amount of numerical information has to be obtained from the drawing

The required data for each different geometric solid depends on its PICASO library equivalent, or on the specified parameters for subroutines developed by the researcher to generate other geometric solids.

Where a surface needs to be determined by listing coordinates of the vertices great care needs to be taken, as the pathway around the boundary of the surface has to be clockwise as viewed from outside. This convention is necessary to distinguish the inside of a surface from its outside; PICASO solids are shell forms. The convention is also of use for the specification of holes in surfaces.

The location of a part has to be determined by reference to its position, this information varies, eg prismatic parts are generated by PICASO with the defined front surface located in either the XY, XZ, or YZ main coordinate planes; the thickness of the prism lies in the negative direction. The distance that will need to be determined is the distance from the appropriate main coordinate plane. This distance is used to move the prism to the desired position. Some designs require that a PICASO generated object is rotated relative to a coordinate axis, eg a pentagonal pyramid is laid on its side so that its usual axis (generated in alignment with the Y-axis) is horizontal. This operation would be achieved by using the PICASO subroutine TURN3D.

6.4. THE EDUCATIONAL IMPLICATIONS OF USING PICASO

6.4.1 THE XYZ SYSTEM AND CONVENTIONS

Unfortunately, there are several problems that are associated with the necessity to introduce elementary analytic geometry concepts into practical descriptive in order to use computer aided design. These problems are not intrinsic but arise out of the existing conventions which appear to be ill-founded. The first problem arises out of the introduction of the XYZ coordinate system and is to do with the orientation of the axes.

Most mathematical texts depict the Z-axis as the vertical axis. This is almost certainly due to regarding the XY coordinate axes from which the third dimension is derived as being on a sheet of paper which is laid down onto a table or other horizontal surface in which case the Z-axis will be directed upwards.

It is quite reasonable to depict the axes in this way as the drawing of XY axes on paper together with the placing of the paper on a table does convey the three-dimensional nature of the axes, but to then propose that this particular orientation is appropriate for relating dimensions to the the individual's perception of spatial relations, is to ignore the importance of the relationship between spatial terms and concepts and the latter's ultimate derivation from the individual's interaction with the environment.

The artist, photographer, draughtsman, or graphic designer would not consider the Z-axis to be vertical as each would view the paper as a picture and the Z-axis would be regarded as corresponding to the forwards and backwards dimension i.e, depth. The use of the term depth of field in photography lends weight to the correlation of the Z dimension with depth. The reader is invited to place a photograph on a tabletop and after studying it, decide as to whether the term 'depth' is perceived as a looking into, an essentially in-front-of relation, or as height.

In addition since it is internationally established by long use that the X-axis is a horizontal axis and the Y-axis is a vertical axis, the depiction of the Z-axis as vertical will confuse many pupils. It is difficult enough to make sure that pupils do not mix up their X- and Y-coordinates without having the additional problem of a different diagram for the XYZ spatial coordinate system. The Americans even use a mnemonic to help pupils remember the orientation of the X- and Y-axes: 'X is a-cross, and Y-wise-up young man'. (or young lady)

The misleading depiction of the XYZ coordinate setup in most mathematics and applied mechanics texts is worsened by the adoption of the convention that the Z-axis should be vertical by the British Standards for Constructional Drawing BS 1192. It is not clear whether this convention has been adopted because of its use in mathematics or because it would appear to relate to workshop practice and terminology used in the engineering industry.

There can be no doubt that the XY coordinate system is a sensible reference scheme. Accepting this means that the Z dimension must be correlated with the term depth not height. But it is worthwhile inquiring as to what is meant by 'depth'.

It is probable that because 'depth' is used in situations where a person takes his or her body **into** a space, that there is the possibility of regarding depth as belonging to more than one dimension. The following examples relate to using depth in relation to the vertical direction: the machinist's use of 'depth' is related to taking a tool into material, the swimmer dives or jumps into the 'deep' end and mine shafts are 'deep'. The alternative of referring to depth in relation to the horizontal forwards - backwards direction is reflected in the following examples: Cupboards and wardrobes are measured in terms of their width, height and depth, and the photographer adjust his lens to obtain maximum depth of field.

The use of the XYZ coordinate system is not in general use in industry apart from where computer aided design has been introduced. The personnel using such equipment probably have no difficulty using right or left handed XYZ coordinate set-ups and can adjust to software that takes the vertical axis as either the Y- or the Z-axis. It is doubtful whether the same can be said for students following higher education courses in design. It is certain that varying conventions will baffle school pupils.

Strangely enough the three dimensions are not of equal value in that two of them are horizontal. This would seem to be an important factor in the design of instruction for descriptive geometry, as it would seem more likely that confusion arises between two views which have a horizontal component spatial descriptor than between two views that do not.

The author has not been able to trace reference to research designed to test the hypothesis that plan and elevation drawings are easier to interpret than two elevations, the latter involve two horizontal dimensions. This is not suprising, because on reflection most of the research has been in the area of instructional media, and on the face of it this present study falls into the same category, but an attempt has been made to look closely at issues that have not been studied before or that have been largely neglected.

The second problem which is related to the first is that even if the XYZ system can be specified so as to arise more naturally from the XY system, there is a convention which is widely used especially in the UK that conflicts with the introduction of the XYZ system. The argument is set out below.

Without developing new instructional material it would have been difficult for the investigator to introduce simple coordinate geometry of three dimensions into teaching practical descriptive geometry as current textbooks are of little use.

Textbooks in the main follow a widespread convention, that is to refer to the intersection line of the horizontal and vertical projection planes as the XY line. This convention is used in examination papers not only for the intersection of the horizontal and vertical projection planes but also for any intersection between planes. Because the XY convention is used in books and in the examination papers, it is unlikely that teachers will employ an alternative method of labelling even if they have misgivings about the convention.

It is extremely difficult to relate the convention to the XYZ system, it is probably a degenerate corruption of the use of 'XYZ' as directions in three-dimensional space to 'XY' because the third projection plane is rarely used in introducing the concept of projection. The convention may have come about because the horizontal and vertical projection planes may have been referred to as planes X and Y. But if so the convention is still unsatisfactory because a view from the X-direction would be an end or side elevation and a view from the Y-direction would be a plan or top view, this is most unsatisfactory as the two views do not relate to each other according to the rule, which is based on good practice, that adjacent views indicate viewing angles of 90 degrees to each other.

The conventional method of introducing projection is to use just a horizontal and a vertical projection plane intersecting at a line labelled XY. The method has been discussed in some depth in Chapter 3 section 3.2.4.2 Arranging Views. Monge's illustrations (in BOOKER 1979) do not use the XY line labelling they use a simple labelling system that is common to mathematical scripts from at least as far back as the 14th Century, that is any letters may be ascribed to any points. There is one notable exception, illustration (ibid p,105 fig 45) included in Appendix 1, fig. 22. This illustration is particularly interesting as in the perspective view part of the drawing the illustrator has used the XY coordinate system notation, (in the XYZ PICASO orientation) but unfortunately has not logically labelled the line of sight lines 'OZ' in the plan and elevation.

The advantage of using letters to label points is that there is no possibility of confusion. Unfortunately, this convention might also hinder comprehension in descriptive geometry as a single point in three-dimensional space may be represented in the same drawing in several views. To label this point in the same way in each view is good communication. But reference to the representation of the point then becomes a problem, unless the appropriate view is also referred to. This is also a problem area in which labels that have some distinct meaning are preferable.

Apart from the introduction of the six-view idea as a means to introduce the arrangement of views, the notion of projection has not been debated to any great extent. There is very little in the Engineering Designer, a British Journal. The Journal of Engineering Drawing (USA) has also, as far as can be ascertained by noting citations - it was not feasible to make a manual search, very few articles on possible different ways to introduce the fundamental notion of projection.

British textbooks still use the same two-plane method, XY line, and four angles. Very little thought seems to have been directed at developing alternative ideas.

One idea that has come from utilising the XYZ system to introduce computer aided design is that each orthographic view results from the invisibility of each dimension in turn from certain positions. For example, from a position that is parallel to the Z-axis only X- and Y-dimensional data is visible. This idea is related to HOOD's direct method but by incorporating the XYZ system it is possible to refer to certain spatial relationships in a wholly logical manner, that is without recourse to terms like: left, right, front, back, side, oblique. These terms are used but by relating them to the axes the pupil can gain a clear idea of what is meant by a front view, it is in fact either a view from X or a view from Z. This description is mathematically definite, provided that the axes are oriented according to the previously defined PICASO convention.

This method of describing spatial relations is one which should have been made use of in mathematics but has not been introduced. In fact mathematics material for schools (Modular Maths, SMP,Smile) refer to orthographic views if at all as plan and elevation, relating it to workshop use. It is a pity that maths teachers have not realised that descriptive geometry offers a major means to gain the interest of so many pupils and is a rich field, topics include: slopes, negative numbers, solids, rotation, translation, inversion, volume, mensuration, loci, trigonometry, ratio, proportion, scale, etc..

It is not that there is a complete blindness or apathy to the use of certain terms to label and thereby indentify the component concepts of descriptive geometry as changes have been introduced. For example, because of the use of varying terminology in reference to views, eg front view, front elevation; top view, plan; plan and elevation (meaning front elevation and plan) etc. BS 308 recommends the use of the term 'view' in conjunction with a letter, eg 'view A'. This does simplify matters but rejects the possibility of labelling views according to the XYZ system. Some of the various methods of labelling projection planes in drawings are described below.

It is difficult to find British books that even attempt to convey the more advanced notions of auxiliary views. It is as if the authors assume that this difficult area of the subject is best dealt with by the teacher. An exception is ABBOTT (1963) and JACKSON (1975). Abbott uses abbreviations for projection planes, subscripted XY lines for the intersection of projection planes, and indicates intersections of planes by traces labelled: VT vertical trace, HT horizontal trace. JACKSON (1975) uses abbreviations for viewing planes and subscripted XY lines. Comparing British and American textbooks it is obvious that there is a greater demand for comprehensive virtually self-explanatory coursebooks in the USA. The American books are consequently considerably more expensive.

In the USA several textbooks have come to grips with the problem of labelling views so as to facilitate teaching. LUZADDER's solution (1968) is to abbreviate the common names for the main projection planes, F for frontal projection plane and H for horizontal projection plane, P for profile plane, O for oblique plane. Luzadder also uses the terms width, height and depth in the same sense as PICASO. SLABY (1976) numbers his views: top view is 1, frontal view 2, profile or auxiliary view 3, etc., and in addition abbreviations are used. EARLE (1972) uses single letter abbreviations for main views and numerals for others. He also uses the terms 'primary aux' and 'secondary aux' for distinguishing auxiliary views.

In Europe PAL (1966) uses letters that have no special significance, eg., K1, K2 for projection planes, and instead of the XY line he uses subscripted X's. GELLERT et al (1975) use similar notation to PAL.

Only labelling which is primarily related to the concept of projection planes and direction has been mentioned. There is much evidence in textbooks that there is a need to relate points, representing some vertex or other, in two or more views to each other.

Some authors use numerals to establish a correlation between related material but problems arise as numerals may be confounded with the concept of shape and measure.

The difficulty that the addition of labelling makes to an illustration is that it makes the illustration more visually complex. There seems to be a limit to how much annotation can be used before what was introduced to help the student becomes a hindrance.

A few authors use the addition of a human figure in the pictorial view to help the student relate to the spatial structure. See Appendix 1 fig: 9, 11, 12-13, 21, 23-28. This idea reduces a complex spatial operation to the concrete level and could be more widely used. As it is not, is it because it is difficult to produce the drawings or because the technique is not considered to be necessary, or because it is little known.

The combination of an unambiguous spatial reference framework, the XYZ system and a human, or human-like figure to which the viewer can relate can fulfill Piaget's advice that spatial concepts need to be related to the concrete, and Bryant's, that the child and most adults need a stable reference framework with which to relate past and previous perceptions.

The problems in developing a computer-generated figure for use in illustrations is discussed in Chapter 7.

6.4.2 XYZ SYSTEM AND GRID PAPERS

The simplest way to incorporate the XYZ coordinate system into drawings is to use square grid paper (5mm quadrille) and the equivalent isometric grid paper. These sectional papers provide the ideal framework for coordinate work. Examples of drawings with XYZ axes are included in the appendices.

The use of sectional papers of the above type is common both here and in the USA. The incorporation of the XYZ system into instructional material is a unique development by the author which is discussed in the next chapter.

CHAPTER 7

THE DEVELOPMENT OF THE COMPUTER PROGRAMS

7.1 THE INVESTIGATOR'S INSTRUCTIONAL MATERIAL

7.1.1 THE USE OF GRID PAPERS

Orthographic drawings can be completed more quickly using square grid paper than by using plain paper. The grid lines enable the pupil to draw accurately by means of a straight edge. Whereas plain paper work requires mastery of the tee square, or parallel motion and set squares.

Whilst it is a valuable craft skill to be able to use drafting equipment, it should not take priority over developing understanding of the descriptive geometry representation, whether this is in the form of the standard orthographic views or some type of pictorial view.

The investigator has based the course on the fundamentals of representation using either orthographic or isometric methods of illustration on work that is carried out using grid papers. There is no serious problem which in the investigator's experience can be associated with the use of grid papers until it is necessary to introduce the concept of the auxiliary view or similar graphical operation to obtain further information from the orthographic representation.

The problem is that the grid lines do underlie, and therefore support the orthographic representation but do not relate to the auxiliary view or other operation, therefore the grid lines are obtrusive in constructions where advanced projection methods are required. However, it is worthwhile engaging in work using grid paper in order to convince the pupil that in certain situations plain paper is preferable.

The addition of XYZ coordinate axes to the orthographic and isometric drawings enables references to be made to specific points without relying entirely on spatial locatives like: left, right, above, out, back etc. Netherless, such locatives are vitally important in forging a bond between the pupil and the spatial configuration and facilitates communication between the pupil and the teacher.

It should be noted that although direction is a concept which does cause problems, the inclusion of XYZ axes in the drawing provides a definite reference which both pupil and teacher can refer to, although the same pupil may still have difficulty with visualising the data to be represented.

It is common practice to devise exercises to accompany orthographic views with a corresponding isometric view. These exercises provide an opportunity for the pupil to demonstrate his or her understanding of the orthographic representation. The XYZ axes provide a common reference framework for both methods of illustration, and of course others.

The inverse operation of constructing orthographic views from an isometric drawing is similarly valuable. In addition, because certain assumptions have to be made, the pupil must think of the problem and make decisions based on those assumptions. For example, the underneath of an isometric view of a spacecraft may not be visible because it has been drawn from above. It can be assumed that there is nothing on the underneath surfaces. Pupils might consider this and decide that they would like to add an undercarriage of some type.

7.1.2 THE XYZ COLOURING IDEA

A further aid to correlating a surface in one mode of communication, eg orthographic, to another mode: isometric is to use colour. The author has developed a colouring idea which is based on colour theory. Each of the dimensions is ascribed a primary colour: red, yellow, or blue.

Stage one involves colouring a cube or cuboid oriented in alignment with the XYZ axes. The top surface (Y) is coloured yellow and also the underneath surface yellow (-Y). The four side surfaces are coloured blue (X, -X) and red (Z, -Z). A worksheet explaining the idea is included with other similar material in Appendix 2. This schematic colouring is also tonal and conforms to the USA Standard for technical illustration. It can therefore be used to help pupils learn to shade their work.

Stage two involves the introduction of sloping surfaces: it is not self-evident that there are just four possibilities. However, the use of the XYZ framework provides a reference framework.

Using this framework it is not difficult to convince the pupil that surfaces slope in only four ways relative to the axes.

The extension of the colouring idea to the four categories of sloping surface leads to colour mixing. The extended colouring idea helps pupils understand the notion of sloping surfaces at an elementary level. Exercises in which work is coloured provides evidence that the pupil can identify surfaces in a one to one relationship between orthographic and isometric views and vice-versa, and incidentally any other method of illustration.

Teachers using traditional methods would be suprised that pupils are not readily able to match surfaces. There are very few strategies that can be employed to channel the pupil into making overt decisions to match surfaces, and most of these, eg labelling identical surfaces in some way, are only suitable for tests.

The colouring idea also provides an opportunity for pupils to recall colour mixing in a context that is closer to mathematics than art. It is suprising how many pupils fail to anticipate what colour will be produced by mixing blue and yellow, etc. Without this basic understanding it is doubtful whether pupils are able to have much control of the creation of colour in painting.

The colouring idea has been applied to work involving auxiliary views. Because the idea is conventionally linked to the XYZ system it is more likely to be employed with a minimum of difficulty than some arbitary scheme. Curved surfaces can also be coloured, this is an unusual application of colouring as it enables a distinct operation: gradual blending, to be compared to a reference framework.

Previous to the introduction of the Colouring Idea the investigator found that pupils had a lot more difficulty with shading. Particularly where an object was to be coloured as well. The PICASO System now has options to apply coloured lighting to a scene, unfortunately it was not possible to try this option.

With the completion of an introductory course designed by the author which utilises the XYZ system and colouring idea, it becomes possible to introduce colouring based on the nature of the object and also computer aided design

7.1.3 SOLID GEOMETRY AND DESIGNS

The descriptive geometry component of technical graphics type courses require not only the representation of surfaces but also the representation of various geometric solids, alone or in combination with other solids and sections of solids.

The rationale for this requirement arises because manufactured articles can be analysed into such solids. Machines can most conveniently be employed to produce: plane surfaces, cylinders, cones, and other surfaces. Designers should therefore, take account of the shapes that machines can economically produce.

This part of the traditional technical drawing courses could be and often was treated independently of real objects partly because there are so many different solids and possible combinations and the complication of different orientations and partly because the drawing of real objects takes more time than the drawing of geometric solids.

Time had to be spent on plane geometry and engineering drawing and as a consequence the extra time needed to develop the pupils' appreciation of the relationship between the plane and solid geometry and engineering and other applications was lacking.

The introduction of Graphic Communication and the new CDT: Design and Communication syllabusses and changes in assessment and course design for GCSE allows a certain amount of flexibility which enables more time to be devoted to descriptive geometry or not according to the preferences of the teacher.

To extract data from drawings in order to employ a computer to generate a model of the design concept requires that designs have to be analysed into component parts and these component parts are classifiable as types of geometric solid. This requirement provides motivation for the pupil to take a keen interest in solid geometry and provides an additional opportunity for the teacher to develop the pupils' ability to analyse a design.

7.2 ANALYSIS OF THE REQUIREMENT FOR COMPUTER PROGRAMS

7.2.1 SPECIFICATION OF APPLICATIONS

The are several possible applications for which computer programs may be written in the teaching and learning of practical descriptive geometry. These applications can be conveniently divided into programs that are designed to enable instructional material to be produced, and programs that enable students to use the computer to generate their design concepts and modify them. Either of these categories can be further split into programs that are interactive and programs that are not. There are thus four categories of program.

7.2.2 ESSENTIAL COMPONENTS OF PICASO PROGRAMS

PICASO programs for three-dimensional work require data in a certain format according to the geometric solid or element that is to be generated. This data is either read from a datafile or entered directly in an interactive type program, the latter can also have an option to read in data from a file if required. Data is usually input by using a terminal keyboard, but could be input from some other device, eg punched cards, paper tape, etc.

In addition to data entry it is sometimes convenient to have a facility to output data to a data file or to some device. Typical situations might include the construction of an object or spatial structure by interactive use which it is intended to save for input into some other program. Another option might be to save an image which has been generated, for use elsewhere. This data would be two-dimensional in nature.

It is also important to enter details about the data. If the data is a pupil's design it will be necessary to enter that pupil's name and tutor group and possibly the school. This category of data could be read from the same data file that is used for the pupil's design, or could be entered interactively.

After the input of data it is usual for some sort of manipulation of the data to be carried out. This might include: joining of a PICASO object with another, rotation, and shifting, Components to set up a viewing position and to frame the image on a display or paper have been mentioned in section 6.3.2 above. The remaining component involves the routines which carry out the image display procedure: plotting on paper or display on a terminal screen.

7.2.3 TYPES OF PROGRAM

The types of program that would need to be developed would in theory cover every aspect of three-dimensional descriptive geometry. Some of the various categories of program are listed below:

1. generation of objects and spatial structures,
2. viewing of the items above in any type of projection,
3. addition of spatial reference aids and notation,
4. multiple view drawings (orthographics),
5. auxiliary views,
6. developments.

Each of the above categories may be further classified into programs that can perform some specific operation. For example, category 4 includes programs for generating two-view, three-view, four-view orthographic multiviews. The possible range of teaching strategies may also require that facilities be incorporated in the above types of multiview to modify the output in some way, eg an option to suppress one of the views (missing views problems).

In addition, it is desirable to write programs to enable routine work to be accomplished by the user. Programs might have to be developed to meet the particular requirements of various categories of user: the teacher, pupils, and the instructional designer. It may also be desirable to include in the categories of user the computer operator, the media resources officer (MRO), or other person who may be employed in the production of drawings.

7.2.4 EXPERIMENTATION AND DEVELOPMENT

Initially various programs were written to learn how to use PICASO's three-dimensional facilities and explore their potential in school. These programs were special purpose, e.g., a program was written to take an object and rotate it to a number of equally spaced positions around a vertical axis. This program was designed with a view to using its output in the investigators classroom, it was anticipated that the pupil would be more likely to understand the form of the object if instead of single views being produced the object was depicted in several positions from one viewpoint. As with single views the pupil has to imagine being in a certain position to obtain the view. See for example, Appendix 3, fig. 14.

No attempt was made to formally identify by a controlled experiment that the hypothesis above was correct. The main drive of the research being to **develop** the means whereby different ideas, strategies and techniques can be employed by teachers, enhancing methods of instruction already in use as well as creating new methods. Unfortunately, most teaching takes place without scientific verification. It is hoped that the development of these new techniques will be of use in further research into the validity of 'old' and new methods of instruction as well as those already in use.

The school's technical graphics club provided the setting for involving a small group of pupils in developing designs for generation by the computer. One of the most interesting designs produced at that time was a spacecraft which had an escape module. It was intended to generate the spacecraft and the escape module. Initially the escape module which was simpler than the main craft was selected for computer work. In order to indentify all of the surfaces of the spacecraft it was necessary to draw six orthographic views. Unlike the ship there were no parts of the craft that could be regarded as being a combination of simpler geometric solids, except for the engine rocket nozzles which were conical in form.

XYZ coordinates of each point on each of the surfaces had to be determined from the drawing and in addition the program had to generate the cones for the engines. Mistakes were made because initially six view drawings were not made and even with six view drawings two of the inner surfaces were not depicted. It was thought that XYZ coordinates of the inner surfaces could be determined without additional drawing. The result being that in addition to an error or two related to location one of the surfaces was entered in its anticlockwise sense. The result of the latter error being that the surface was interpreted as being invisible.

The pupil's design was far from simple, consisting of several skewed or oblique surfaces. This meant that it took a lot of time to develop the computer-generated version. Even so the project attracted the attention of other pupils and the attendance at the club, which was after normal school hours, increased. A poster was produced using the computer (Appendix 3, fig. 1.)

Because of the amount of work involved in writing special purpose programs, or modifying existing programs to enable certain forms to be generated, a decision was made to work towards a general program which would be capable of generating a variety of forms.

7.3 TRIAL DEVELOPMENTS

7.3.1 INTRODUCTION

It was found that computer-generated pictorial type views needed to be supplemented by orthographic type main views in order to check the data. If a mistake has been made in data entry a listing of the data file may be compared to the original data, but if a mistake has been made in the preparation of the data it is usually necessary to obtain a computer produced two- or three-view drawing. This drawing can be inspected to find exactly where the error is and the correspondng part of the data checked. Although PICASO has facilities for producing orthographic views it does not have a routine that will produce multiviews. The frequency with which mistakes are made in preparing data was found to be such that it was essential to produce a plot (computer-generated drawing) for each new design.

The program that was developed to check work included automatic production of a two-view orthographic and a pictorial view together with indentification of the work and the designer. For convenience this program has an option to select the paper size. In addition as often more than one design needs to be checked a facility to continue to plot other designs was incorporated in the program.

The following commentary on various programs discusses the development of the work in realationship to pupil project work and instructional design.

7.3.2 CUBOIDS PROGRAM

This program was developed to enable objects that could be analysed into a collection of various cuboids to be undertaken. Since the cuboid is a simple rectangular block-like shape it is suitable for projects of an introductory nature. The City Unit 1 project was designed specifically for the cuboids program. See Appendix 2, Items 10-11. for a copy of the project sheet for the City Unit.

The Cuboids program uses the PICASO routine BOX to generate the cuboids. BOX generates a cuboid in the positive octant of the XYZ set-up with one corner located at the origin. The dimensions of the cuboid are entered as width, height and depth corresponding to the directions X, Y, and Z. If the desired cuboid is located somewhere other than with one corner at the origin then a call to another routine is needed to move it from its generated position. The cuboids program is designed to generate cuboids in any position, provided only that the cuboid is aligned with the XYZ axes. To do this, in addition to width, height and depth data, the program requires the XYZ coordinates of the nearest corner to the origin. This corner is the left-hand bottom rear vertex of the cuboid.

In addition to preparing a two view orthographic drawing of the design the pupil also has to label each cuboid, mark the appropriate corner of each cuboid that is nearest to the origin and prepare a list of the data. To facilitate this a data preparation sheet was designed. (see Appendix 2, Item 12.)

The City Unit 1 project was evaluated and developed by offering it to second- and third-year pupils. Initially only third years taking graphical communication did the project. Later with revision of the data preparation sheet and the introduction of an additional simpler City Block worksheet (see Appendix 2, Items 7-8.) designed to be used in a CDT type lesson it was possible to offer the project to the second year. The second-year work differed in that the project was intended to be part of an introductory course in practical descripive geometry. This project work will be discussed next.

The pupils first used a set of wooden blocks to develop a satisfactory design. They did this by assembling their blocks on a preprinted XYZ coordinate sheet developed by the investigator. This sheet was novel in that the pupil's model was placed in the XZ plane of the XYZ coordinate set up which was part of the sheet. This position corresponds to the plan position for third angle projection orthographic drawings. (see Appendix 2, Item 9.)

When pupils were satisfied they drew the front elevation of the model in the XY plane on the sheet. In practice this was more conveniently done by using another printed sheet. Next they completed the plan. For both of these activities they were instructed to view their model from the appropriate direction. These instructions were demonstrated and great care was taken to encourage the pupils to position themselves so as to see the appropriate view. The relationship between what they view and the drawing as a technical type drawing was made explicit by the requirement to draw the blocks in their full size using the grid on the prepared sheet. The blocks were deliberately made so that their actual dimensions could be interpreted onto the grid paper as being 3, 5, and 9 units (5mm grid). The problems associated with measured drawings were thus minimised whilst the drawings that were produced were accurate according to the principles of descriptive geometry.

The pupil's design drawings were next used to create a personal three-dimensional model in wood using 15x25 section timber. As pupils finished their model they were instructed to prepare the data for the computer. In practice this meant that the least able pupils did not do the computer part of the project, but it also meant that the majority of the pupils gained some insight into what was required.

The pupils were also instructed verbally to draw an isometric view of their model using isometric grid paper. The special viewpoint that is required was explained by refering to the model and to the orthographic drawings, which had been coloured according to the XYZ colouring idea.

The computer produced pictorial and orthographic views were compared to the pupil's drawings. One or two pupils who had a lot of difficulty with producing the orthographic views made the model first and then attempted to produce the views. The investigator prepared the data from these pupil's drawings for the computer produced views which were used to help the pupils draw the isometric views and in an extreme case assist the pupil to complete the orthographic views. The instructional sheet has illustrations produced by computer. Colour could have been used to help the pupil understand the views more easily but apart from a few that were coloured by hand the colouring of the views was not feasible at the time.

The third-year City Block project is more complex than the second-year project in that the pupil is not limited to using blocks of a certain predetermined proportion. The project is thus more challenging and is more likely to result in the production of impressive designs. See Appendix 3, figs. 2-3. for examples.

Because pupils had to prepare data for the computer they were involved in unusual activities. Activities that are similar in some respects to spatial ability and reasoning tests. These activities subject to supervision can be considered as possibly contributing to the pupil's understanding of orthographic views.

First the requirement to analyse the design into cuboids is valuable as it requires what can be described as a type of three-dimensional thinking ability. Second they had to match each cuboid's representation in both orthographic views by labelling, thus demonstrating that they have an understanding of the representation. Difficulties sometimes arose because of errors in the pupil's drawing, the labelling requirement thus helped the pupil discover inconsistencies in their work. Next the requirement to identify which corner of the individual cuboids was nearest to the origin provides another opportunity for the pupil to study the orthographic views.

The notion of 'the nearest corner to the origin' necessarily involves both views of course. This is made explicit by the listing of the XYZ coordinates of the particular corner of each cuboid. If the pupil has neglected to think about the activity he or she may find on making the list that a coordinate is missing, eg if the pupil has only marked the corners nearest the origin in the top view the Y coordinate will be missing.

Some second-year groups have also completed the City Block project without going on to prepare data for the computer. Whilst it was not within the scope of the investigation to compare these two groups except informally it was evident that there was extra interest in the project for the groups that had computer drawings in addition to their models.

Whether the pupils who did the preparation for the computer gained in understanding of orthographic drawing and improved their spatial understanding is a matter for further research. But the investigator was astonished at the demonstration of spatial ability that many second-year pupils demonstrated. Some pupils seemed capable of drawing the requisite views from their models even when the models were placed virtually upside down to their drawing. The planning of the project, involving specially prepared grid paper, instructional sheets that had computer produced views instead of isometric views, and the requirement to make models, together with the demonstrations enabled the pupils to have a very clear idea of what he or she was expected to produce.

Third-year work was more interesting as the relaxation of limits as to the proportion of the cuboids resulted in more complex designs. Pupils were not asked to limit their designs to a given number of cuboids and in a few cases this meant the entry of up to two hundred decimal numbers for pupils designs by the investigator.

Some pupils used their computer-generated views as a preliminary drawing, adding colour and extra detail by hand. In one notable example an error made by the pupil, listing the height of a building block as 1100 instead of 11 lead to an interesting computer drawing which the pupil used as material to devise a wondrous structure. It is important to note that provided each cuboid has the three specified dimensions, no matter how large or small, it will be generated. This means that where it is desired to have an area of grass or a path or roadway the height of the grass, e.g., 0.060 (taking one unit as a metre) or other feature can be listed. Similarly a TV aerial or radio aerial can be generated.

Some of the most advanced work required additional drawings to gain data or ensure the design was relatively error free. These designs could be very difficult to check and on occasion the designs were not checked but simply plotted and given back to the pupil to check. This reveals another possible use of the computer so far not mentioned that is that the computer could replace the function of the teacher to check work. Design work places a heavy work load on the teacher. There are times when the automatic verification by computer that a design is error free is most welcome. Neither the teacher, the pupil, or the rest of the class likes having to wait until work is checked, and it is not often that work can conveniently be taken home to check.

7.3.3 PRISMS PROGRAM

Although a suprising variety of designs can be synthesised from collections of cuboids the extra modelling power that is made possible by the use of prisms of various shapes makes the facility to generate prisms important. Cuboids are of course a type of prism and can be generated by the prisms program almost as easily as by the cuboids program.

The prisms program makes use of the PICASO routine THICK which takes a shape determined in the XY coordinate plane and gives it a thickness in the negative Z-dimension to make it into a prism. The investigators program manipulates objects generated by THICK so as to cater for prisms facing any of the XYZ directions.

As with the cuboids program a special data sheet was devised for the program. A project based on spacecraft was selected. The process of analysing a design to yield the requisite information is quite complicated, and to enable pupils to proceed with the work with a minimum of guidance from the teacher a flowchart was devised. The flowchart type worksheet for the spacecraft project is included in Appendix 2, several examples of spacecraft designs are included in Appendix 3.

The spacecraft project was offered to second-year pupils in the technical graphics club as well as third, fourth, fifth and sixth years following the technical drawing or graphical communication course.

The analysis of a design into prisms was for many pupils quite difficult. In addition to the worksheet several examples of spacecraft designs were shown to the pupils, and solid prisms (of the regular type) were also used to help pupils understand the geometric form of the prism. Even so difficulties arose. Some of the difficulties were due to the nature of the restrictions imposed by PICASO routines, which were due to either program restraints associated with hidden-line logic, clockwise oriented surfaces, convexity of forms, and other factors, eg the limit on vertices of prism faces to not more than 8.

Other difficulties were due to descriptive geometry, either the geometric or graphic components or both. The principal geometric problem was misunderstanding what is meant by the term prism. Pupils were quite likely to include a form that was not a prism, perhaps part of a pyramid or wedge. Sometimes as often as not this was as much due to the pupil conceiving a three-dimensional design concept which although basically prismatic in form had some forms that were not prismatic. It should be born in mind that even when a pupil has a clear concept of a prism he or she might not be able to conjure up a design that consists entirely of prisms.

Where a pupil had managed to draw correctly his or her design which had additional non-prismatic forms a decision was made to either alter the design or not. In the case of the latter this decision was taken because the design would have been most probably spoilt by excluding the non-prismatic forms. Either the pupil was shown how to prepare data to generate the non-prismatic forms or the investigator did this work.

7.4 EVALUATION OF PROGRAMS

Two types of difficulty were identified those that are computer based and those that are geometric in nature. These difficulties need to be discussed to determine to what extent they hinder the pupil's development or are beneficial. But first certain problems that are more closely related to drawing should be discussed.

The use of grid paper for the design work helps to minimise difficulty with the drawing to the real problem, that of representation. Many pupils have difficulty with representing prisms because they attempt to indicate the prism faces in the plan view in some way or they try to indicate sloping surfaces. It is too easy to equate these errors with a misunderstanding of the geometry as they might arise for quite the opposite reason, i.e., because of the pupil's desire to communicate geometric features even though this results in a distortion of the orthographic representation. FREEMAN (1980, p. 346)

The restraints that are placed on the teacher and pupil by the computer, in this instance by a non-interactive program, needs to be considered but there arises a difficulty here as usually the solid geometry component of technical graphics courses is not so evident. More often than not the teacher of technical graphics is likely to treat the solid geometry aspect almost as a separate subject. British textbooks are not particularly helpful as there are very few examples of the employment of geometric terms to describe the component parts of real objects. Either the geometric forms are not mentioned or are treated separately. The same can be said for examination papers, very rarely is there a question that requires an analysis of an illustration of a real object into its component geometric forms, although there is usually a question where the pupil has to identify individual geometric forms.

Yet the development of analytic skills in relation to spatial structures depends on a fundamental understanding of solid geometry. Not as the study of a collection of theorems but more as a scientific study of real objects, models, and drawings and the mathematical terms that are needed to discriminate between different geometric forms and spatial elements. According to SKEMP (1971, p.83) the ability to handle concepts depends to a considerable extent on having a range of symbols which label or otherwise represent those concepts. Geometric terminology provides just such a range of symbols to think about spatial configurations and communicate to others. It is most unfortunate that geometric terminology has a classical derivation as many pupils find such terms alien.

The intention to use a computer to generate a design makes knowledge of geometry essential and the additional requirement of extracting data from the design drawings entails teaching pupils not only how to represent certain forms but also how to extract relevant data. It follows that the use of correct terminology is vital, particularly where the design consists of several types of geometric form. The setting in which the terminology is used is thus much more acceptable to the pupil.

The necessity to restrict the pupil's designs that are intended for generation by computer to cuboids or prisms or other combinations depends on the pupil's ability to represent a design and extract data and other considerations which are dealt with later. The restrictions are thus quite reasonable provided that certain exceptions may be made, as explained above. The same restrictions applied to project work that is not intended for the computer would be harder to justify to the pupil, and probably would not occur to many teachers unless they had a mathematical background.

With computer-based design work the geometric nature of three-dimensional design is evident to the pupil no matter what is designed and therefore the pupil is motivated to study the various geometric forms. It is difficult to imagine how design work that is not related to computer generation of the design can be so intimately related to three-dimensional geometry

Current teaching practice, as far as can be ascertained at present, does not stress the importance of geometry in three-dimensional design. What is stressed is the importance of geometry in drawing, i.e., in manipulating instruments to draw shapes. Given the three-dimensional concept the pupil does have to realise his or her concept in the form of a design and this ultimately depends on the ability to draw, and drawings are shapes, which are two-dimensional in nature. Unlike the mathematics teacher, the technical graphics teacher must rightly be concerned with pupils who have problems with drawing. Whether the stress placed on two-dimensional geometry, possibly at the expense of three-dimensional geometry, is misplaced is a matter for further enquiry. The cuboids and prism programs do to a certain extent remove the necessity to produce a finished drawing, the design sketch on grid paper being sufficient, subject to the requirement that the geometric content of such sketches be absolutely accurate. In their original form both the cuboids and prism programs do not produce complete hidden-line drawings, as they were designed merely to check that design data is correct. Complete hidden-line removal being a time consuming option. The three-dimensional data generated by the computer being output to a data file which could be input to some other program to produce whatever type of drawing that is required.

Although the programs provide an opportunity to base three-dimensional design work on solid geometry, they do not provide any special facility for pupils to learn descriptive geometry as they are not interactive. But it should be borne in mind that the programs were developed primarily in order to provide a facility for developing illustration for instruction.

Since the investigator usually tries to incorporate the best of the pupils design work into instructional material it was only natural to extend the use of the programs to pupils. Because of the interest shown in the projects and the value of the work in stimulating an interest in solid geometry it was decided to offer the projects to all of the investigator's third-year teaching groups each year.

In the next chapter the development of a general program to generate cuboids, prisms and other forms is discussed together with other programs.

CHAPTER 8

THE PROGRAMS

8.1 INTRODUCTION

8.1.1 THE TYPES OF PROGRAM

Several different types of program as listed in Chapter 7.2.3 have been written, the only exception being on the topic of constructing developments. In addition to large programs consisting of a few hundred lines of code or so, there are several smaller programs.

Some of these programs involve problems that still need to be resolved. The nature of the problems are discussed under the entry for each program. A brief description of the most important programs follows.

Guide sheets for the main subroutines which were written by the investigator for this study have been included in Appendix 6. Subroutines and functions are refered to in the text as PICASO routines if applicable.

8.1.2 THE SOLID MODELLER

The prisms program and the cuboids program share several subroutines the difference between them being in the type of data and in the geometric form produced. By incorporating a keyword in the data and an alternative path in the main program it was possible to merge the two programs into one and also provide a means to generate other forms. The development of the main program to generate designs, the solid modeller, was relatively straightforward once the general form of the program was conceived.

8.1.3 THE INTERACTIVE MODELLER

In addition to the solid modeller a program was developed to enable manipulation of three-dimensional data interactively.

8.1.4 THE GLASSBOX IDEA

A program was developed to generate a 'glassbox' onto the sides of which orthographic views could be placed. This 'box' is a PICASO object, i.e., a three-dimensional data model which is compatible with other PICASO objects derived from the PICASO library. PICASO objects can be viewed, just as if they are real objects, from any direction.

The glassbox being a general program can accept any object and produce images of the object on its sides. This program was intended to provide one of the principal computer generated models for developing instructional materials.

8.1.5 ORTHOGRAPHIC VIEWS

Several programs were developed to generate orthographic views. As the plotting of a multiview drawing involves careful placing within the area reserved for drawing the routines that have been developed to assist arranging views are discussed under the heading Orthographic views.

8.1.6 FRAMEWORKS

This category includes programs and routines that were developed to provide spatial reference aids to support instruction.

8.1.7 TEXT

Text is necessary for identifying work and to accompany illustration meant for instruction.

8.1.8 AUXILIARY VIEWS

Although the problem of generating auxiliary views has been investigated problems associated with other programs had an inhibitary effect on the development of a general program to generate auxiliary views.

8.2 SOLID MODELLING

8.2.1 INTRODUCTION

The term solid modelling is commonly used to describe software that generates three-dimensional data corresponding to the regular basic geometric solids and their combinations. This software typically includes options to create other geometric forms by various operations. According to WILLIAMS (1972, P.203) there are ten principal methods which can be used to generate new forms. Only a few of these operations seem to be relevant to technical descriptive geometry, they are: distortion, dissection, and rotation-translation. PICASO has routines to enable these operations to be performed.

The term solid is slightly misleading because many systems generate either wire frame solids or shell forms. The wire frame modeller displays images which take account only of the vertices and linking edges of the solids. Shell forms are capable of displaying forms in their solid representation by bringing into operation a hidden-line removal routine, however, if such forms are cut by a plane into two parts each part would no longer be a convex solid as the interior would be visible where cut. PICASO objects are shell forms, and the PICASO SYSTEM can operate with or without hidden-line removal. Certain problems arose in relation to PICASO objects being shell solids, these are discussed later.

8.2.2 OBJECTSYN1

8.2.2.1 INTRODUCTION

The solid modelling program that was developed, OBJECTSYN1, inputs data from a disk file in the users area and according to the nature of the data generates a PICASO compatible three-dimensional object consisting of one of more parts. The object can be optionally displayed and or plotted and output if required to a data file.

The structure of the program is discussed section by section below.

8.2.2.2 DATA FILES

Each data file has a heading consisting of information about the datafile. Just as a drawing needs to be indentified with the pupil's name, tutor group, title, and date; it is even more important that work meant for the computer is identifiable.

Work stored in a computerised retrieval system cannot be casually looked through to find some piece of work. Database management must be orderly to ensure that data is easily retrieved and removed when no longer required. If the work for several pupils is to be plotted together details need to be to hand. Even with a school based computer it will be unlikely that the majority of work can be carried out with the pupils present.

In addition to the above items of indentification it was considered that the name of the school should be included together with a unique identification for the design. The latter consists of six characters (the maximum FORTRAN variable length). This label could be similar to a drawing number or relate to the users interest in some other way. The method used by the investigator is best presented in the form of an example:

OB8414

Identifies a datafile's contents as being a PICASO object, designed in the year 1984, and it is the 14th design to be added to the main data file. The latter needs further explanation.

The disc file storing the data is accessed by a routine that asks for a data library filename. This enables data to be added to a main file to suit the user. In practice files were formed for each year, for specific purposes, eg testing programs, and also for certain individuals. OBJECTSYN1 opens the specified disc file and searches for the appropriate data. If it is not convenient to put the data into a main data file a temporary six character filename must be entered as the first 'line' in the data.

According to which keywords have been used the following data as it is READ into OBJECTSYN1 will enable the program to generate each of the required geometric forms. Each form is joined together, as it is generated, with the previously generated forms. A keyword situated after the data determines the end of the datafile.

In addition to the multiple generation of various geometric forms other keywords enable routes to be opened in the main program to code which, for instance, treats groups of data as a unit, which can then be rotated as a whole, but separately to other forms in the same data file. Those keywords related to treatment of the object to be generated as an assembly which still need to be thoroughly tested have been restricted to a duplicate program called ASSEMBLY. Other keywords are discussed below.

8.2.2.3 TYPES OF OBJECT

The following types of objects which are easily synthesised from the PICASO library are available to the user:

Cube, cuboid, prism, cylinder, pyramid, cone, sphere

The other regular solids: the tetrahedron, octahedron, dodecahedron, and icosahedron have been catered for in the program called SOLIDS. The reason for keeping the regular solids separate are discussed below. (8.2.4)

Several of the other PICASO objects are not objects in the sense that they consist of surfaces. Each object in the real world is visible because it has surfaces or area. It was found that PICASO library routines that did not have surfaces, eg DOT3D, LINE3D, did not plot accurately with complete hidden-line removal routines as the logic involved takes account of area. In addition it was found that there is a need to generate very thin geometric forms such as cylinders, and although these forms can be easily generated by existing PICASO routines if the form is at a compound angle to the XYZ axes, it became very difficult to generate. As a consequence it was necessary to write new routines to generate these special spatial objects. These are discussed below.

8.2.2.4 SPECIAL OBJECTS

LNE3D

This subroutine was written to generate a three-dimensional model of a line. The model is generated as square sectioned cuboid which usually is very small in relation to its length. The required data consists of parameters for the thickness, and the XYZ coordinates of each end.

This routine is especially useful in the generation of oblique fine lines. It was extensively employed to realise the 'Deep Space Craft' (Appendix 3, Fig.16.) which required thin struts.

THINCY

This subroutine is identical to LNE3D except that there is an extra provision to vary the sectional form of the 'line', e.g., it could be triangular or hexagonal in section or by entering a sufficiently large numeral could be equivalent to a cylinder

PLATE

This subroutine was written primarily to generate a rectangular plate or sheet given: the thickness of the plate, its length, and the XYZ coordinates corresponding to the middle points of its breadth. It generates a CALL to PICASO routine BOX and rotates the generated form into the appropriate position. The routine thus conveniently enables a cuboid to be oriented when its angular position is unknown.

FACET

This subroutine generates a surface from XYZ coordinate data read from a disc data file and like other OBJECTSYN1 routines joins the surface to other PICASO objects. This routine is necessary to enable three-dimensional designs that have parts that cannot be synthesised from other PICASO library routines to be generated.

In theory this subroutine is all that is required to generate an object, but in practice it should only be used where no other easier routine can be employed.

8.2.2.5 OPERATIONS

OBJECTSYN1 has facilities to carry out various geometric operations on the generated object. This is accomplished by locating keywords in the data file to direct the flow of control in the main program to the appropriate routines. Variables are initialised in a common area in the main program and are thus made available to relevant subroutines enabling or disabling the operation of certain procedures.

The following subroutines allow for certain options to be brought into effect:

CUTOFF
This subroutine provides an option to access CUT3D in order to enable dissection to take place. A keyword in the data enables the parts which are cut to be closed by generating a new surface. As noted above, PICASO objects being shell forms become open where they are cut, this may be undesirable.

Unfortunately the closure option does not work properly and there was insufficient time to rewrite the relevant malfuctioning code. However, CUTOFF works and has been used to realise several designs see Appendix 3.

ASSINF & ASSOPT

These two subroutines enable individual or groups of objects that are being generated by OBJECTSYN1 to be operated upon as an assembly. The operations available include, dissection, rotation, translation, and reversal of an objects surfaces to create a negative solid, which can, for instance, if the solid is a cylinder, be regarded as a hole. Both routines are CALLed from OBJECTSYN1 by keywords in the datafile.

8.2.2.6 PLOTTING

When the object has been generated it should be drawn in order to enable the data to be checked for accuracy. OBJECTSYN1 enables the object to be displayed or plotted using subroutine CHEKDW Specially generated three-dimensional axes (see Frameworks 8.8 below) are added to the object to assist the checking procedure. These axes are unlabelled at present, but the teacher may add the labels if required. The plot size is A4 in the landscape position. A pictorial drawing is generated using subroutine FOCLPT to establish a reasonable position for the eye, and scaled to suite the picture area using DRWSC3. The pictorial view is supplemented by a two view orthographic drawing. The mode of operation is partial hidden-line removal, for speed of excecution.

Datafile identification is added to the plot by utilising STRINGLIB this is made easier by using the following functions: PLWSTR, PLWCH, and PLWPX. (see examples in Appendix 3)

8.2.2.7 OUTPUT

After plotting, the three-dimensional data is output to a datafile (filename of the users choice). A data file containing the designers identification details are also automatically output with the prefix: TX supplemented by the year and the number of the design (according to the original datafile identification).

8.2.3 ASSEMBLY

ASSEMBLY is a duplicate of OBJECTSYN1 which is meant to ultimately replace it. ASSEMBLY includes routines to manipulate data to generate complex spatial structures. Linked parts of a three-dimensional design concept can be rotated relative to each other. Owing to the possible incorporation of code that may not work as intended OBJECTSYN1 has been modified in stages only after satisfactory tests have been carried out using ASSEMBLY. Thus the solid modeller is functional but still under development.

ASSEMBLY is also valuable in developing and determining operations that may also be carried out by the interactive program OPTIONS reviewed below (8.3.1).

8.2.4 SOLIDS

With the exception of the cube the regular solids do not figure prominently in technical design. Although some pupils would most probably include such forms in their designs given the opportunity.

It is quite difficult to draw plan and elevations of the regular solids, therefore if pupils would like to include such solids help will be required. The position of any particular regular solid could be drawn by deciding where the centre of the solid should be and merely drawing a circle, which would represent the circumscribing sphere. This strategy coincides with the manner in which the PICASO library routines generate the solids, in terms of their radius rather than their side.

SOLIDS takes account of the possible requirement of specifying side length rather than radius. The addional problem of working out the variety of orientations that may be desired has been defered.

SOLIDS also includes an option to generate frustrums of pyramids. Unlike OBJECTSYN1 SOLIDS operates by entering data from the terminal.

8.3 INTERACTIVE MODELLING

A program that works in an interactive mode provides two-way communication between the user and the computer. It is true that there are very few programs that do not require some user input, but a program that can be regarded as being truly interactive allows the user to exercise various options immediately after the previous choice has been executed. Such a program has a command language. This can be quite simple consisting of commands like DRAW or INPUT and their abbreviated forms DR and IN. That is provided the results of such commands result in clear simple information being displayed as to what needs to be entered, and has the facility to enable the user to check what has taken place.

8.3.1 OPTIONS

The program OPTIONS allows a user to enter a filename for a three-dimensional object, generated by OBJECTSYN1 or some other method, and view it from any position in either an orthographic mode or pictorial mode. The object can be modified by joining another object to it, and other operations. For instance, an object could be entered, saved, moved in some way and joined to the saved version, and moved again, etc.

All of the main PICASO operations are available to OPTIONS. An on screen prompt enables any option to be selected. Since the range of spatial operations, constructional operations, and input-output operations are limited in number it is not necessary to reserve part of the VDU screen for a continuously displayed menu, but by typing HELP or HE, or he, an on screen annotated menu is displayed.

The various options relate to the functional requirements of the program. It was realised at the outset that schools would be most unlikely, for some time to come, to have terminals with graphics capability of sufficiently high resolution to make the design and development of an interactive program feasible. The principal objective of the program was, therefore, to provide the investigator with the means to interactively develop spatial structures and designs.

Care was taken to develop OPTIONS so that it would be based on known good practice. OPTIONS was developed without the benefit of knowledge derived from the considerable development in computer technology and the subsequent increasing interest in interactive programing.

The factors which need to be taken account of in the design of interactive programs are now becoming clearer. In addition to the growing literature on interactive computing a considerable amount of work has been done by writers of microcomputer software for home use. The latter is well worth close scrutiny, several home computer journals regularly review software. Comments are made on 'user friendliness' which is an appraisal of how convenient such programs are to use. The further development or replacement of OPTIONS with a program designed for use on colour high-resolution terminals in a school environment will need to be based on current research, and a survey of the existing varieties of interactive program design.

NIEVERGELT et al (1986) make the point that all to often the design of interactive programs is taken from considerations of hardware and the programmer rather than from the user. Their book provides detailed guidance on the design of interactive programs from the point of view of the educational user. It appears the main problems are reducible to informing the user of the state of the system, and rectifying mistakes. They point out that often mistakes are fatal and that notwithstanding inclusion of messages that query the user: delete? please confirm Y/N, etc, mistakes are made, and almost by definition mistakes are unavoidable. Therefore provision should be made in interactive programs to recover the previous state of the system. The latter is usually accomplished by providing an UNDO command, ideally this should enable all previous commands to be UNdone back to the beginning of the session. In practice this is difficult owing to the enormous overhead in terms of memory that is required.

OPTIONS does not include a command to UNDO but a PICASO object or spatial structure can be saved within the program to enable further work to be effected on the identical structure in the working area. For safety the user is advised to WRITE the saved version to a disc file, ready for input to the working area if the existing version is spoilt in some way. In addition a structure may be input to a permanent part of the working area for use perhaps as a reference for changes that have been effected.

The various commands available to OPTIONS are grouped according to classification of function which relates to three distinct areas of the program's memory:

THE WORKING AREA

The working area is used to enable operations to be carried out on a PICASO object.

THE SAVED AREA

The saved area is used to copy a PICASO object from the working area as modifications are made. Additional objects can be joined to any object stored in the saved area. Data can only be output to disc from this area.

THE PROTECTED AREA

The protected area is used for reference puposes. A PICASO object that is entered in this area is immune to change. It can be drawn and will not be automatically erased. Thus a three-dimensional set of XYZ axes can be drawn to enable an object to be compared to it, or an object which is meant to be part of something else may be checked to see if it has been manipulated correctly.

A complete list of the commands and their function is included in Appendix 5

8.4 ORTHOGRAPHIC VIEWS

8.4.1 INTRODUCTION

A number of programs have been written to generate orthographic views of any PICASO object. Most of these programs could be reduced to one main program which would be capable of generating from one to six orthographic views, depending on the requirements of the user.

In practice individual programs for generating two, three, four, and five views were developed. There were several reasons for adopting this approach. First it was easier to control factors which might produce errors by working in discrete stages. Second the method chosen, after several trials, used a considerable amount of memory, and the alternative approach would have resulted in more time being spent on computation. As the latter was at a premium a decision was made, for the time being, to select the quicker and easier approach. Finally the ideal program, based on an analysis of geometric concepts and various alternative methods of teaching would need to provide at least the features listed below. Work on incorporating these facilities is made easier with a simpler program.

8.4.2 SPECIFICATION FOR AN IDEAL ORTHOGRAPHIC VIEWS PROGRAM

The ideal program would need to provide at least the features listed below:

OPTIONAL ARRANGEMENT OF VIEWS

1st and 3rd angle representations, and second and fourth angle projection; to enable the student to realise why only projections in the 1st and 3rd angles are acceptable.

SPACING OF VIEWS

A facility to select automatic spacing of views relative to the paper proportion, and size. An option to overide automatic spacing, perhaps to include explanatory text.

ROTATION OF THE OBJECT

A facility to rotate the object prior to views being generated in order to fit the object conveniently on the paper, and to enable alternative front and top views combinations to be studied.

AXES

An option to include XYZ axes, and combinations of one or two axes selected from XYZ. This option would enable the principles of orthographic projection to be discussed in relation to framework cues, and could be used by the teacher to test students. See also the next item.

SUPPRESS A VIEW OR VIEWS

A facility to suppress the drawing of one or more views in any of the standard positions. This option provides the teacher with the means to generate his or her own missing view problems. Suppressed views should also be available if required, to draw or display separately, and an option to include axes in the missing view position.

LINEWORK

A facility to draw outlines, hidden detail, centre lines, etc., in an appropriate type and thickness of line. Option to suppress automatic execution to specified views and generally.

AUXILIARY VIEWS

An option to generate a 1st, and 2nd auxiliary view with optional automatic spacing.

TEXT

A facility to include text anywhere on the drawing, and optionally automatically with certain views.

TITLE BOXES

Optional facility to draw borders, title boxes, and associated text.

8.4.3 GENERAL METHOD ADOPTED FOR PROJECTION

The general method used for setting up the PICASO object in order to derive the orthographic projections is based on a strategy used to explain how views are obtained. This strategy is based on rotating the object to face the viewer. It is therefore the inverse of the glass box idea. The orthographic programs rotate copies of the object by 90 degree increments to face the front (the Z direction), these copies are moved so as to be equally spaced from the front view. At present the programs do not include optional spacing, the views are moved by an amount which is a suitable spacing distance. This spacing distance is automatically calculated and is based on the size of the object and its proportions.

An instructional-type sheet which is illustrated by a computer generated perspective drawing of the effect of these rotations and translations is included in Appendix 4, Fig. 25. Note the five-orthographic view drawings should have been three-orthographic drawings in order to match the spatial arrangement views below them.

The PICASO subroutine ORTHO is used to set up an orthogonal viewing position. Since orthographic projections will be generated to a scale of 1:1 the spatial structure which might consist of up to 6 objects, depending on how many views are required, has to be scaled to suit the drawing. The spatial structure is regarded as a single PICASO object by using PICASO routine JOIN. The scaling operation is carried out by subroutine OSCALE.

8.4.4 DRAWING THE VIEWS

The process of drawing using a computer is usually called plotting, and the drawing is refered to as a plot.
The subroutine METRIC has been written to facilitate the setting up of the plot size using metric A sizes. In addition another routine LNDOPT enables the so-called landscape orientation of the plot to be set. At present the orthographic views programs only make use of METRIC and LNDOPT although other routines have been written to facilitate other options these are discussed in Section 8.8 below.

8.4.5 ORTHOGRAPHIC VIEWS PROGRAMS

The following programs have been written:

TWOVIEW, THREEVIEW, FOURVIEW, FIVEVIEW, SIXVIEW

A utility subroutine to enable the user to select which combinations of views relative to the XYZ coordinate axes has yet to be written. At present this facility is effected by using OBJECTSYN1 to rotate the object relative to the axes. Similarly reference aids such as, three dimensional axes, are generated by XYZAXE (see 8.7), and other special object generating programs discussed below. These programs would, subject to further work being sanctioned, be rewritten as subroutines for use in the orthographic views and other programs.

An optional facility to output the generated spatial structure to disc has been included so that perspective and other pictorial type views may be made for instructional purposes. This option is particularly important as the purpose of developing programs to generate orthographic views is to provide material that can be utilised for instruction.

For example, using PICASO program CUSHN An animated film could be made using the structure, possibly in conjunction with a human type model (see the Robot in Appendix 4, Fig. 16.) and model XYZ axes.

Programs to generate plot text have been developed see Section 8.8 below. The inclusion of text was one of several important modifications which were defered for the present, text being added by hand where plots are to be used for instructional material.

8.4.6 AUXILIARY VIEWS AND THE ORTHOGRAPHIC PROGRAMS

The development of the spatial configuration by multiple copying and rotation of the datum object provides the basic idea for generating orthographic views. These are commonly considered to be main views, that is orthogonal projections onto picture planes which are normal to the XYZ coordinate axes.

Auxiliary views are orthographic views which are projected onto picture planes which are inclined to the axes. Auxiliary views could thus be generated by extending the method in the following manner.

Further copies of the datum object need to be made for each auxiliary view. Each copy is rotated according to the pre-selected viewing angle and spaced apart from the other views.

The second auxiliary view, which is necessary in order to represent surfaces in their true shape that are oblique or skew to the coordinate axes or principal projection planes may be effected by copying and rotating the first auxiliary rotated copy, which acts as an intermediate stage. By saving the model to disc the whole spatial configuration may be used to generate pictorial illustration of what is regarded as the most difficult concept to teach second only to work on mining problems. (SCWEINFURTH, 1969)

No reference could be found that anyone has made a three-dimensional model of such a spatial arrangement for helping the student understand how the second auxiliary view is derived. Even reference to second auxiliary models that employ images and a Model are few: MILLS' students models were, as mentioned above, very elementary, far too abstract for school use (MILLS, 1970). The excellent article on constructing models by McGUIRE et al., (1949) gives detailed plans for making models to explain the derivation of the second auxiliary view. But although it would be worthwhile making such a model, a lot of work would be necessary to provide models and corresponding views of a range of interesting objects. And these models only provide one way of thinking about the manner in which the views can be derived. That is by surrounding the object with view planes; an operation that is related to moving around the object.

The alternative as described above of rotating the object does not seem to have occurred to anyone. This might be because no one has seriously considered making such a model, which would be extraordinarily difficult to make, as the models would need to seem as if they were floating in air. Therefore the computer generation of a model that may be viewed from any direction is of considerable importance.

Unfortunately it was not possible to develop the programs to realise this particular method of generating auxiliary views. This was due, primarily, to the time and difficulty associated with developing programs that were of greater priority. The initial objective being to develop programs that would support the teaching of the most fundamental concepts, and secondarily to problems associated with developing other methods of generating auxiliary views; which were tackled first. These are discussed in Section 8.6 below.

8.5 COMBINED VIEWS

VIEWOBJECTS is a program which generates a pictorial view and two orthographic views of an object. The program enables work to be checked quickly and has facilities for multiple plots.

The program is quite compact making use of various subroutines. The principal routines being: SEARCH, and CHEKDW. CHEKDW has been mentioned above, Section 8.2.2.6, and SEARCH is discussed below, Section 8.9.

8.6 THE GLASSBOX PROGRAM

The GLASSBOX program was written to generate a transparent box onto which orthographic projections relating to the six main viewing directions could be drawn.

In its initial development the PICASO SYSTEM only catered for limited hidden-line removal. This meant that in certain situations it was necessary to use AUTOPROD, a special purpose program developed at North East London Polytechnic for generating pictorial views of three-dimensional objects.

The early versions of the GLASSBOX program were written without transparent projection planes. In fact the projection surface has to be non-existent except in the form of a set of distances; these being the distance of each corner of any object from the projection plane. These corners together with the edges connecting them have to be condensed into a flat plane which has to be located so as to appear to rest on the imaginary projection surface, i.e., they have to be co-planar. Originally the projection surfaces were made by generating very thin cuboids. But since these were solid it was not possible to view the object as well as its projections. The AUTOPROD generated plots enable the object inside the box to seen by employing the conventional code for hidden detail: the dashed or broken line. Appendix 4 contains a model church in a glassbox produced by using AUTOPROD. It is obvious that except in certain situations that type of illustration would be unsuitable. Consideration had to be given, therefore, to developing other ways to model 'glass'.

Since without reflections glass is only visible because of its edges, ways of depicting the edges of rectangular sheets were pondered. One attractive idea is to think of the sheet as being non-existent except for its frame which could be made of very small section square strips. The sheet would appear to be present if a view was projected to lie in its plane. Adopting this idea subroutine BOX3D was written. Using the cuboidal frame generated by BOX3D projected images would appear to be on 'perfect' glass surfaces. Even reflection marks could be added to the plots if necessary by incorporating oblique extra fine lines using LNE3D in the plane of the 'glass'.

The illustrations in Appendix 4 generated by the GLASSBOX program help to convey how useful such illustration could be. But on closer inspection it will be found that the hidden-line routine has failed in this unusual application, the projected view is in fact an object with no thickness. The same problem was encountered with auxiliary views which will be discussed next.

8.7 AUXILIARY VIEW PROGRAMS

8.7.1 INTRODUCTION

Objects and structures that are cuboidal in form consisting either of an aggregate of cuboids or have been carved out so as to resemble an object that is analysable into cuboidal volumes only requires orthographic views to determine its form. Additional views in the form of sectional views might be required if the object or structure is very complex. But objects and structure which have sloping surfaces may also need auxiliary views to determine the exact shape of some surfaces, or partial auxiliary views to determine the shape of a surface or the length of some part or other. Similarly objects that may be considered to be fabricated from sheet material and which have curved surfaces which intersect each other may need an auxiliary view to determine the development. As has been mentioned above auxiliary views are difficult to understand. These difficulties have not been investigated, practioners admit that the topic is fraught with difficulty but do not suggest why the student has problems. This is partly because the topic is difficult by nature. It is not an elementary concept. There is no carefully researched hierarchy to refer to only agreement that the topic is troublesome.

The topic needs to be considered in terms of the psychological as well as the mathematical factors. But it has not been deliberately considered from both viewpoints. The relationship between the person viewing an object and the object ultimately can be reduced to either the person moving around the object or the person moving the object. It is not possible to move a large object, therefore, the person has to move around the larger objects to view them and so derive knowledge of their form. Smaller objects may be handled, and quite naturally the person will move the object to gain an understanding of its form. There are consequently just two ways in which to inspect an object to gain knowledge of its form, and these are related to the type of object. It seems reasonable to propose, therefore, that the teaching of the auxiliary view concept should include methods that relate to the two ways of viewing objects. These two ways may conveniently be classified into the active and the passive.

A means of developing material that is related to the active way of viewing objects has been outlined above. The alternative approach will be discussed next. The investigator has developed material which is based on the passive way of viewing the object. As this involves moving around the object, view planes have been placed around it, and the pupil is invited to think about the views that he or she would see as if they were to move around it. (see instructional sheets in Appendix 2, Items 21-24.)

In order to stimulate attention a house was chosen as the subject. The house is also suitable as it is a large object. The rationale for developing these particular sheets is that it is the belief of the investigater that the main difficulty with teaching the auxiliary view concept is that there are two alternative paths of travel around an object from above. Thus considering the examples, views may be taken only once in relation to the horizontal plane, but twice in the vertical: around the X-axis or around the Z-axis. There is, therefore, a likely cause for confusion to arise. The illustrations were quite time consuming to develop and they depict only one object. The reason why only part of the possible ring of views has been drawn around the Z-axis is that one would not normally see the underneath of a house. In order to try different objects it was decided to write programs that would generate auxiliary view rings around any object. The programs will be discussed next.

8.7.2 THE AUXILIARY VIEW PROGRAMS

This discussion will be fairly short as the difficulties that precluded satifactory development of a general program to generate rings of views around any combination of axes has already been mentioned above. The problem was in hidden-line removal, neither PICASO or AUTOPROD could produce error-free plots.

The material that was produced is of interest though. Particularly the attempt to resolve the problem by generating objects that were approximations to projected views. These were actually copies of the object that were moved to the projection position and compressed to be 'flat objects' the technique almost worked, but in order to achieve a satisfactory plot the objects had to be so thin that errors appeared once more. Appendix 4 contains several drawings which were produced either by one of the auxiliary views programs or by FLATOBJECTS referd to above. Other work in this area is discussed in Chapter 9 in conjunction with pupil work.

8.8 FRAMEWORKS

8.8.1 INTRODUCTION

It is not possible to design (by drawing) three-dimensional objects without having some knowledge of solid geometry, but this knowledge may be inaccessible to conscious thought processes; as although it manifests itself in terms of the students capability to produce a design, it is often not coded into a recognisable mathematical form. It is thus difficult for the teacher and the pupil to communicate.

The pupil demonstrates his or her understanding of the requisite geometry by creating a drawing. If this drawing is faulty, the pupil's performance needs to be analysed. The errors might arise from misapplying the rules of representational drawing or to lack of visualisation, or to gaps in the pupil's understanding of geometry, or which is often the case to a combination of these types of error.

Several strategies may be employed by the teacher to gain insight into the pupil's difficulty. If the teacher decides that it seems certain that the pupil has developed a three-dimensional design concept, and has previously had no significant problems with drawing, it seems likely that the pupil has some difficulty with the geometry.

The pupil must be helped yet the pupil's ability to discuss work using mathematical terminology may be inadequate. There is thus a need to link up the pupil's powers of visualisation with mathematics.

The process of deliberately having to think in terms of aggregates of geometric solids which is essential for computer aided design using PICASO provides a partial link. But the language and ability to discriminate between various solids falls short of the full requirement for communicating in the wider field of projective geometry. It is helpful here to take a closer look at the nature of mathematics.

SPENCER-BROWN (1969 P.xiii) regards the discipline of mathematics as: '. . a way, powerful in comparison with others, of revealing our internal knowledge of the structure of the world, and only by the way associated with our common ability to reason and compute.' and further on (p.xv) he likens mathematics to psycho-analytic theory: ' In each discipline we attempt to find out, by a mixture of contemplation, symbolic representation, communion, and communication, what it is we already know.' considering the elements of this mixture, as abilities that need to be developed, the ability to use symbolic representation is what is most difficult to provide for the pupil, and is what many pupils lack. The importance of this ability has been mentioned above by SKEMP (see Section 7.4).

The other abilities are more general, provided that the pupil is motivated, and has confidence and respect for the teacher, they need not present a problem.

It has been suggested above that the student's motivation can be increased by using objects which are exciting (see Section 5.1.6), eg land, sea, air, space vehicles; hi-fi and optical equipment; the pupil's own room, house, flat, garden, local environment, etc. If these objects can be related to the development of project work that is itself interesting to pupils, not only will the pupil be well motivated but he or she will respond positively to the teacher.

The development of the child's cognitive system has been discussed above (Section 2.2). Objections were raised to some aspects of the educational implications of implementing Piaget's theory, in particular, Ausubel's concern that the importance of reception learning in the development of the individual's ability to employ knowledge is undervalued. KLAUSMEIER and SIPPLE (1980 P.32) disagree with Piaget's theory for similar reasons. Their research suggests that the deeper understanding and greater use of the same concepts at the successively higher levels is more a product of learning and experience than of maturation. They have developed The Child Learning and Development Theory in which they establish four levels of learning related to the use of concepts, these are: concrete, indentity, classificatory, and formal levels. It is important to point out that the first two levels are treated by many psychologists as discriminations not concepts, or they may be grouped together (Gagné regards them as one: concrete concepts).

Apart from the level at which concepts may be understood concepts are classifiable in a number of different ways, for mathematical concepts the classification of concepts into concrete and abstract is necessary. If the defining attributes of any particular concept can be perceived that concept is classified as concrete, otherwise it is abstract. The latter can also be regarded as a defined concept. Principles may be defined formally as a relationship between two or more concepts. Not only must each concept which is part of a principle have to be understood but the relationship has to be understood as well.

The most fundamental relationship expressed in the various principles that form that body of knowledge known as geometry is the class of axiomatic relationships, which consists of: fundamentals, laws, rules, theorems, and axioms. If the concepts that are part of these items can be modelled so as to become more concrete it follows that the principles will be easier to learn. The basic elements of descriptive geometry as defined in Section 3.3 can be related to the XYZ coordinate system as discussed above. But unlike three-dimensional models, or drawings which depict three-dimensional objects, these elements are abstract, but can be made less so by modelling. This can be accomplished by techniques that support the apprehending phase of learning by 'added differential cues for perception' (Gagné's table in Appendix 1).

Programs were written to enable these elements to be utilised to provide support for the XYZ system, and the various elements of geometry. The programs are discussed below and their use in Chapter 9.

8.8.2 PROGRAMS AND SUBROUTINES

XYZAXE and AXIS SUBROUTINES

XYZAXE is a subroutine which generates XYZ coordinate axes as a three-dimensional object. XYZAXE CALLs subroutine AXIS which can generate either X,Y, or Z axes or all three.

The arrow heads are regular pyramids which may be generated with any number of sides. They are generated by a CALL to PICASO subroutine CONE. The arms of the axes are cylinders generated by a CALL to PICASO subroutine CYLIND.

The axes and arrowheads are set by XYZAXE to enable AXIS to generate four-sided cones and cylinders in order to minimise the amount of storage required, bearing in mind that these coordinate axes are PICASO type objects. The axes are automatically scaled by XYZAXE in relation to the mean size of the three-dimensional object or structure. The arrow head diameter is set to one third its length in conformity to British Standard 308. But arrow heads are not part of the Standard axial line, they are included to support instruction.

The coordinate axes arms are not generated as a type of chain line in conformity to the Standard because each part of the chain line would need to reserve 98 units of memory. To generate a three-dimensional PICASO type object which is similar to the Standard axial line would take a very large amount of memory.

AXISQ SUBROUTINE

AXISQ is an interactive type subroutine similar to AXIS above. AXISQ may be incorporated into either interactive programs like OPTIONS or other programs.

BOX3D SUBROUTINE

BOX3D has been refered to above in relation to the GLASSBOX program. It is interesting to note that the box which of course exists as 12 edges, requires nearly 1,200 memory units.

CRATE PROGRAM

CRATE merely generates a cuboidal box the same size as any PICASO type object. Its purpose is to generate a simple model of an object for use with work that involves generating a collection of objects that may be checked for a suitable arrangement faster with a set of cuboids rather than the objects. It is also meant to assist in the teaching of proportion in three dimensions.

PLANES SUBROUTINE

PLANES generates three-dimensional planes in the form of frames like BOX3D which are separate data objects. The routine is intended to be used for generating views onto the 'planes' and for rotating these projection planes in order to provide models for teaching orthographic projection.

8.7.3 PROBLEMS

It was intended to write programs to generate several types of three-dimensional PICASO type objects which model each element in applied descriptive geometry: points, lines, hidden lines, centre lines, section lines, axial lines, limits of movement lines, and lines of symmetry, etc. The work involved is relatively straight forward, except where various types of line intersect and abut objects, but it was not feasible to proceed because of the very large amounts of memory required.

The case studies discussed in Chapter 9 and present developments in computer technology which are discussed in Chapter 10 provide good reason to proceed with the development of the programs.

8.9 TEXT

8.9.1 INTRODUCTION

Programs and subroutines were developed to enable text to be incorporated in plots. Text not only makes identification of plots possible but also provides an opportunity to complete instructional material entirely on the computer.

STRINGLIB was used to generate the text. STRINGLIB is a library of several different fonts which has been developed for plotting. Each letter in a font has to be drawn out just like any other shape. Consequently text has to be positioned and care taken to ensure that it fits into the required location.

Fortunately various subroutines were available to minimise the amount of work required. (see Section 8.2.2.6)

Since the text is plotted the process is relatively slow, much slower than a daisywheel printer and to a much poorer quality but the alternative, typewritten text, which then has to be cut and mounted is suprisingly time consuming, especially where titles are added using stencils.

Particular applications are discussed in greater detail in Chapter 9.

8.9.2 THE PROGRAMS AND SUBROUTINES

DRAWTEXT AND DRAWTEXT2

DRAWTEXT2 supercedes DRAWTEXT which was designed to plot views generated by other programs. The text identifies the designer and the establishment, in this case a school, where the work originated. See Appendix 3 for examples.

It was found that it is more convenient to READ a text data file than to type in information. In fact the latter operation often takes far more time than the whole plot.

The simplest way to create the textfile was to generate it from the source datafile. Subroutine SEARCH may be used to search a data library for the appropriate data file, relevant information is READ from the file and a temporary text file with the prefix TXT is created by SEARCH. All the user has to enter is the name of the data file. On occasions it may be desirable to enter information directly in which case DRAWTEXT may be used. A multiple plot version, DRAWTEXT2.MULT, enables several plots to be undertaken without having to reposition the plotter head.

DRAWTEXT and DRAWTEXT2 CALL subroutines TITLE1 and TITLE2. The latter has been used in other programs notably VIEWOBJECTS.

FRAMES

FRAMES is a program which plots from one to twenty drawings. The drawings are set out in rows and columns according to data which is entered into a special data file. Text may be added anywhere within the area of each frame set up for each drawing. The text is also READ from the data file along with the name of each plot file. See Appendix 3 for examples.

OPTLET AND OPTCON

Subroutine OPTLET enable text to be plotted according to: height of letter, ratio of width to height, and type of font. Subroutine OPTCON enables an option to continue plotting text which is necessary if the current PICASO FRAME is moved, and or changed in size. OPTCON accepts commands which may be shortened to two letters. The command HELP, or HE,or he, CALLs subroutine HELPTX which displays a guide to the various commands that are available.

Text that is entered or READ from a file may include special markers to enable bold type to be selected and one or more blank lines to be placed after the current line of text.

8.10 CONCLUSION

Difficulties were encountered with the development of programs that generate views of an object either onto an orthographic main projection plane or some other plane. The problem is to do with complete hidden-line removal in its application to a two-dimensional view which has been made solid by PICASO routine THICK. Even in cases where the third dimension has been set to a non zero amount it is not possible to obtain completely error free plots. This means that in every application that involves views being projected, those views being made part of the three-dimensional structure, and then being subject to further projection problems arise.

These problems are due to the way that PICASO has been planned. PICASO was developed to be compact, and not unreasonably slow in operation, this meant that certain restrictions were made. These include the absence of routines to calculate the intersection of PICASO type objects with each other.

This means not only that the completely automatic generation of illustration involving pictorial views of projection operations is not possible but also that the modelling of some objects consumes more time and ways of thinking about design in terms of removal of solid volumes is not possible. Nethertheless, the work that can be accomplished is considerable and is discussed in the next chapter.

CHAPTER 9

CASE STUDIES

9.1 INTRODUCTION

This part of the study reviews the computer programs in action and discusses various examples of instructional design and pupils' work in relation to the different settings in which the work was carried out. Reference to the investigator's instructional material as some worksheet or other, requires explanation. the term 'worksheet' has varying meaning within the context of the classroom. In general the term refers to a consumable single sheet, often used in conjunction with a workcard, booklet or book. The investigator's instructional material consists of single or double sheets that are not consumable in the above sense. The sheets have been designed to incorporate all necessary information and resemble worksheet material in the above sense in that every attempt has been made to ensure that the pupil actually carries out some task which can be readily observed. It is intended that the material be assembled in a publishable form at some future date, in the mean time the 'pages' are referred to as 'worksheets'.

9.2 INSTRUCTIONAL DESIGN

9.2.1 Introduction

Several pieces of work that were generated by computer for instructional purposes are closely related to pupil project work in the sense that the instructional material was developed to assist with the particular project or topic. **Spacecraft 2** refered to in section 5.1.7.5 above is a typical example which is discussed in greater detail below. This type of application falls into the category of Project or Topic Drawings.

Other drawings were produced to assist in teaching specific ideas, the most important example being The Glass Box Idea. This type of application has been classified as: Three-dimensional Concept Drawings.

A third category: Experimental Drawings includes work that cannot easily be classified in either of the above ways.

9.2.2 PROJECT OR TOPIC DRAWINGS

The first example to be discussed is the computer generated drawings which were produced to accompany the Spacecraft 2 worksheet. The reader is advised at this point to refer back to section 5.1.7.5 as this sheet was discussed in some detail in relation to drawing exercises. Copies of both the old and the new worksheets are included in Appendix 2.

The replacement of the isometric view of the craft with two perspective views accompanied by orthographic views forces the pupil to think about the three-dimensional nature of the object.

Prior to the introduction of the new sheet many pupils tended to copy the isometric view without thinking about its three-dimensional nature. In addition to the reluctance that some pupils had to modifying the design, there was also a tendency to make errors particularly with the far wing. Drawing the far wing of a space or aircraft requires the plotting of points which are common to the wing and the body. This is difficult because these points are most likely to be not visible. This particular problem is just one example of a type of problem which is of course common.

Each point on the far wing has to be located in order to draw the part which is visible. The simplest way to find these points is to measure, or count the required number of units equivalent to the width of the body from the points where the visible wing meets the body. The other points representing the vertices of the far wing are then plotted and the visible part of the various edges drawn. Depending on the pupils previous experience about three quarters need to be shown how to find the points on the other side of the body.

It is by no means easy and simple to employ what would appear to be nothing more than common sense to solve this problem. The reason for the pupils' difficulty is somewhat complex, but should be discussed as it indicates areas where instructional aids need to be developed.

The construction of a drawing which is representative of a three-dimensional object involves an interaction of two distinct modes of operation: interpreting the three-dimensional form of some object or structure according to the individual's understanding of geometric knowledge into information which is used to record the object's form in the two-dimensional plane of the paper, and dealing with the emerging view of the object or structure as it is drawn.

The latter constitutes an extrordinarily complex activity as there has to be an interplay between visualisation, knowledge, and graphic skills. At one moment the drawing is perceived as a three-dimensional image, albeit in the form of a picture or view, and at another moment the drawing must also be perceived as a two-dimensional diagram, partially obscured by the hand, the ruler or set square, and uneven lighting in the room.

Inconsistances in the drawing such as construction lines which are too prominent, and an error or two add to the likelihood of further mistakes being made.

In addition, the process of drawing is subject to more complex perceptual factors which increase the possibility of errors. For example, although grid lines help to provide a structure they also present an even field which can hinder perception, especially if the grid lines are too strong in colour and or tone as the lines which constitute the drawing must compete with the grid lines. A pupil might have difficulty simply because he or she has selected a 6H pencil rather than a more suitable H grade pencil. The individual carrying out the drawing may also manipulate, usually by rotation, the paper to faciliate his or her performance, this may result in lines being drawn in the wrong direction.

These possible impediments, and others, are related to psychological factors which are partly developmental and partly characteristic of the perceptual apparatus. According to FRISBY (1979) it is possible to note several areas where problems might arise. The brain is likely to be misled by configurations that give rise to optical illusions, these include: spatial distortions, brightness contrast, ambiguous figures, camouflage effects, and after images. Real scenes give rise to a number of cues to depth: masking (near objects obscure far objects), texture gradients (nearer elements in a texture cast larger images than those further away), shading, position of similar objects in the field of view (objects that are further away are higher in relation to the ground plane), and linear and aerial perspective. Drawings have varying amounts of such cues.

Exactly to what extent it is possible to determine whether a pupil is visualising and thinking in terms of three-dimensional geometry when copying an isometric or other pictorial type view is debatable. In the investigator's experience the completion of isometric views which involve partially hidden parts does provide an oppportunity for visualisation and thinking about three-dimensional geometry to take place, especially where information has to be obtained from orthographic views.

Faced with several pupils who have difficulty with creating isometric views from orthographic views, or completing partially finished isometric views it is all too easy to allow them merely to copy a completed isometric view. The development of a computer program that provides for the inclusion of extra depth cues in various types of view would enable a range of instructional material to be developed.

Even where the pupil has overcome the perceptual problems and is able to visualise the geometric form of the object there still remains the problem of producing the drawing. Visualisation in itself is insufficient, there has to be operational capability to solve the graphic problems.

An operational capability to solve the graphic problems involves mobilisation of the pupil's ability to visualise together with an ability to gain and employ knowledge about the object's geometric form by means of several strategies. In the case of isometric drawing, the relationship between the orthographic views and the production of an isometric view is that of plotting in three-dimensions and recording this information in the two dimensions of the paper by a mathematical mapping. The character of which is learnt by studying examples, copying, drawing from blocks, and more rarely by explicit teaching of the mapping. The use of grid papers provides a framework for establishing the character of the mapping. Plotting involves an ability to extract the dimensional information from drawings and by measuring record the position of various points and connect these points to form edges. The pupil has, of course, to cope with hidden-line removal as well.

The task of measuring is reduced to counting where grid papers are employed. Even so, it is quite easy to make mistakes. The investigator has found that the easiest strategy to use is to place the pencil point on a grid point and count and move the pencil to the next grid point, repeating the procedure till the correct number of units has been plotted. A small circle drawn around the terminal grid point helps to ensure that mistakes are not made in connecting up the points. Pupils finish their work in black ink, (usually using a ball point pen, which are quite cheap) the pencil circles and other preliminary lines can be erased when the ink is dry, which usually takes less than ten minutes. The use of ink not only enables the pupil to finish a drawing to a higher standard but the additional operation of picking up the pen to go over a pencil drawing helps to establish the habit of thinking about the process of drawing as one of construction.

It would therefore be useful to incorporate a facility which provides in computer-generated illustration similar strategies which teachers employ to assist their pupils. These would include options to mark or tag certain key points on the surface of a three-dimensional PICASO type object, and also add extra points, reference lines, reference planes, and reference surfaces. To enable the pupil to grasp the relationship between certain points or other features of the object and one or more of the following: axes of symmetry, cuboids and other geometric solids which enclose a part (and thus simplify the drawing of that part), horizontal or vertical reference lines (eg perhaps a reference line which touches the front edge of a spacecraft wing). In a program such as OPTIONS these elements might optionally be made to flash, or could be highlighted in some way.

The new Spacecraft 2 worksheet is placed in the investigator's scheme of work for the pupil after curved surfaces. The justification for including the worksheet is partly in the opportunity that it provides for pupils to develop a more interesting design than was provided by Spacecraft 1 and partly because of the new topic, which Spacecraft 2 introduces: the partial view. Not only is the top or plan view drawn as a partial view but the pupil is warned that he or she may need to draw partial views, and that this might be necessary even with A2 size paper.(PD 7308 the abridged guide to BS 308 includes the topic, see Appendix 1.) The topic also provides an example of computer-generated design which pupils were offered later. See Section 9.3.2 below.

The notion of a partial view is not easy to teach: the investigator has not found one British textbook which has examples of partial views, yet there are several instances during the school year where pupils produce work which requires partial views. The partial view also provides a link to the notion of sectional views and is an example of one type of convention used in drawing, as such it may help to discriminate between other types of conventions, eg break lines.

This worksheet provides the average pupil with about four lessons work. The pupils have as supporting material examples of designs produced by other pupils, these are located on the wall displays; and in addition, as mentioned above section 5.1.7.5, a kit of cut-out geometric forms have been made to enable different ideas to be tried without actually drawing.

It is convenient at this point to discuss the instructional material that was produced for the Spacecraft Project. The project enabled pupils to develop designs which were subsequently generated by computer. The first page of the instructional material introduces the topic and provides computer-generated illustrations of four examples produced by pupils. The text on the page was also drawn by computer. Because of the rather complicated nature of extracting and preparing the necessary data from the drawing a flowchart was devised to enable the pupil to proceed without an initial explanation. The Spacecraft Project instructional material is located in Appendix 2. along with other material referred to in Section 9.2.

The project limits the pupil to designs which consist only of prisms. These face either the Z-direction or the Y-direction, the body is assumed to be aligned with the X-axis, thus the prismatic faces of the parts that form the body face the Z-direction. A computer-produced illustration of the body of the craft was supplied to assist the pupil visualise the relationship of the body to the axes. This illustration was produced initially using AUTOPROD as conventional hidden lines were required. The outlines and axes were added by hand. The rationale for designing the project instructional material in the form of a flowchart is discussed in greater detail in the section on pupil project work.

Two computer-produced perspective drawings were produced for the City Unit 1 project. These views depict the example from slightly different positions. It is quite obvious that the production of this type of illustration would be most unlikely to be undertaken without the benefit of the computer. The axes were generated as solid objects, only the labels being added by hand. Note that 'X' is hidden, a cue that is considered to be of the framework type.

Computer-produced illustrations were also produced for the last example to be discussed: the City Block Project. Two perspective drawings were produced and a standard third angle projection orthographic plan and elevation. The fourth illustration is an auxiliary plan type view that was included to stimulate interest in the notion that many other types of view are possible.

The project work related to the above instructional material is discussed in greater detail below.

9.2.3 THREE-DIMENSIONAL CONCEPT DRAWINGS

The instructional material discussed in this section relates to the use of computer generated graphics which were developed to teach specific topics. The examples are usually used as reference material supplementing worksheets.

The possible advantages of using different methods of illustration to depict the same object were discussed in section 5.1.7.4 above. Three types of pictorial method: isometric, oblique, and planometric were used to illustrate: a chair, building, robot head, and the space shuttle. The three types of illustration were plotted together with accompanying text. These sheets are used to help pupils discriminate between the different methods.

The chair and the building are computer generated copies of objects that are used in the investigator's worksheets. They are therefore, objects which the pupils will have studied and drawn (isometric and orthographic views only) previously. This facility enables course content to be related to both the teacher's instructional material and pupil project work, and should therefore, have distinct advantages over commercially produced graphic material that is unrelated to either.

The material represents just one variable in the process of representation, that of the application of different methods of drawing an object. The computer could be used to produce material related to all the other variables, eg rotation of the object, change of position, perspective.

The difficulty in producing correct views of an object and locating those views on a projection surface has been discussed in section 8.6 above. In practice this meant that work that could have been produced to help the pupil understand the notion of an orthographic view was postponed. Several examples produced by the GLASSBOX program were used to provide pupils with material that they could think about, but it was not considered that the material could be studied closely; consequently, exercises were not developed using such material. This was the most disappointing aspect of the research.

9.2.4 EXPERIMENTAL DRAWINGS

A number of drawings which were produced to explore various ideas are worth inclusion as they help the reader to understand the nature of some of the difficulties, and provide a better understanding of the extent of the work undertaken. The examples which are discussed below are included in Appendix 2

FLATOBJECTS referred to above in the section on auxiliary view programs (8.7.2) was used to produce a series of views which would illustrate how by compressing one dimension a main orthographic view could be approximated. In practice, errors occurred when the flattened object became very thin. The examples show a perspective view of the spatial concept, note how effective the use of the three-dimensional axes is.

FLEET was designed to enable a number of identical objects to be spaced according to the users requirement. In practice, this program was made somewhat redundant by OPTIONS. The examples of Spacecraft 6 show two quite distinctly different views of a fleet. Subroutine BOXIN was written to enable various arrangements of complex objects, like Spacecraft 6, to be plotted quickly and economically in a simpler form. BOXIN generates a 'crate' or 'box' which just holds the object, ie, its overall dimensions. The program is valuable for linking the study of proportion in three-dimensions in an interesting way to pupil's work. The example shows BOXIN being employed to simplify a fleet of Spacecraft 6.

The DELTA project involved developing a series of spacecraft with a delta style wing. Each craft consists of intersecting geometric forms. The pupils were given worksheets consisting of incomplete orthographic views of each craft. The pupils had to complete the views by determining where the various edges of the wings intersect the body of the spacecraft. Each worksheet is increasingly harder. Computer-produced pictorial views of the spacecraft were available for the pupils to inspect either after they had finished a sheet or to resolve a problem. In the case of the latter, the pupil would only be shown the pictorial view as a last resort, as the pictorial views are particularly efficacious.

Similar work could be developed using different objects, eg tents, or buildings. The possibility of the pupil interactively modelling similar interesecting forms using a library of geometric shapes is a worthwhile future development that springs to mind.

Work involving determining the true shape of an oblique or skew surface tends to be not only difficult to teach but also boring for the pupil. In the opinion of the researcher this is due to selecting an object which is too abstract. The pupil cannot visualise the spatial orientation of the object. One approach is to provide part of an object that the pupil can easily think about, eg a spacecraft, or at a more mundane level a set square shaped triangle. Both these objects were used to teach how to determine true shape.

The space shuttle was used as an example of a type of object which can be readily visualised by the pupil. Since the views of the complete shuttle would need to be drawn quite large to allow an individual body panel or part to be selected for determining its true shape, it was decided to divide the shuttle into two parts. A computer-generated model of the shuttle was divided by using subroutine CUTOFF just behind the nose section which was selected as the object from which the pupil was requested to determine the true shape of parts of the cabin area. The pupil drew on the computer drawing, which although only part of the shuttle needed to be plotted A2 size, and was further assisted by the use of the XYZ colouring idea. Since the pupil had an illustration of the complete shuttle as well as the nose section to refer to he did not find the object too abstract to visualise.

Starting with a pre-drawn object enables the pupil to concentrate on the task in hand. Although it was not feasible to carry out much work using this technique owing to shortage of time it seemed that the facility to provide parts of an object for true shape determination is worthwhile.

The other object which was used, the 30/60 degree set square, was first rotated using OPTIONS, three-dimensional axes were added, and the resulting object drawn as a five-view orthographic drawing. Since the pupil knows that the triangle should have the familiar set square shape it was anticipated that the exercise would have greater interest and be more effective than using a triangle that is unrelated to the pupil's experience.

Owing to lack of time this experiment was not implemented, but a drawing showing the constructional steps is included in Appendix 2 for reference. Note how the addition of labelled axes helps to orient the triangle by providing cues to the vertical and horizontal directions.

9.3 PUPIL PROJECTS

9.3.1 Introduction

Pupil project work consists of work that was given to all the pupils in a group or only to some pupils. In the case of the latter, work was often carried out after school or at lunch time. In order to develop project work for a group it was necessary to initially explore possibilities with a few pupils. much of the work was undertaken with younger pupils, rather than with examination groups. This was mainly due to the lack of time to develop further projects based on third-year work, but a further impediment was the additional work required to enter the pupils' data into the computer. Even so, some work was accomplished by examination groups and assessed as part of their CSE coursework. Pupils who were entered for GCE did not gain any credit for computer or any other coursework, this was due to the limitations imposed by the GCE Boards in that coursework is not assessed in Technical Drawing or Graphical Communication. The new GCSE syllabuses allow coursework assessment and in recognition that the computer is becoming extensively used in industry syllabuses include opportunities for computer-based work.

9.3.2 GROUP WORK

The City Block Project

The City Block Project was designed to enable young pupils to design and make a model of part of a city, a city block. The educational objectives of the project include the acquisition of workshop skills associated with working with wood as well as technical drawing skills, and the extension of the concept of plotting in X,Y coordinates to plotting in X,Y,Z coordinates. The experience gained by offering this project reinforced the necessity to relate the use of coordinates X,Y,Z to width, height, depth respectively. The project is offered as an example of the integration of drawing, craft, and mathematics. In regard to the latter, some work was carried out with a small group of pupils as part of their remedial mathematics work.

The aim of the project was to provide as many pupils as possible with a computer-produced perspective drawing of their individual models and to use these views as an additional aid to produce isometric drawings of their models, within a reasonable period of time. Work was carried out mainly with 2nd year pupils but some 1st years also completed the project.

The worksheet for the project is included in Appendix 2 and has been refered to above (Section 9.2.2) The project restricts the pupil to the use of timber of the same cross-section, this allows for the initial use of pre-prepared blocks which the pupil uses to complete the two-view orthographic drawing, and generally simplifies the project.

The worksheet is designed to enable the project to be carried out without using the computer if necessary, and without actually measuring, cutting, and joining pieces of wood together. However, the computer-produced perspective views help pupils to construct their own isometric views and provide a valuable opportunity to relate mathematical work to both drawing and craft work.

The examples shown in Appendix 3 include several designs that were produced both with and without the restricted use of the same cross-section timber. More complex examples are the product of the next group project work to be discussed, the City Unit 1.

The City Unit 1 Project

Third-year technical graphics students were offered a more advanced version of the City Block project. Removing the neccessity to make a model frees the pupil to design without regard to the difficulties that he or she would encounter if the design had to be constructed. The restriction pertaining to choice of size and proportion of the basic cuboid constructional element was also removed. The main restriction was that pupils were asked to use A3 size grid paper, and that no cuboids should be angled relative to the XYZ axes. The number of cuboids that a pupil may use was not restricted.

A pro forma was developed to enable the pupils to record the appropriate data for generating the computer model. It was found that pupils were less likely to make mistakes if the size of each element was recorded before the coordinates for positioning each element. It was suggested to the pupils that they might find it easier to record the width (the X dimension) of each cuboid before recording the height, etc. Some pupils did work in this way, but it is difficult to ascertain whether this technique would be generally easier.

It was originally intended to design a larger part of a city using a number of units, but at the time the very large amounts of data that would constitute such a project deterred further progress. The possible design of a repeating unit or a combination of units, possibly using mirror replicas had to be deferred. The various examples in Appendix 3 illustrate the range of ideas that were developed by pupils. About 80 designs were produced including City Block work.

The Spacecraft Project

The Spacecraft project was offered to third-year technical graphics pupils as either an additional project to Spacecraft 2 or to replace Spacecraft 2. The major difference being that the Spacecraft project enables a perspective view to be drawn automatically, and that the preparation of the data provides an opportunity to think of three-dimensional design in terms of aggregates of geometric forms.

The project worksheet was designed in the form of a flow chart because this was found to be the most suitable means to provide the pupil with the necessary instruction, bearing in mind that the groups were taught by means of worksheets.

It was necessary to restrict the design work to structures that could only be synthesised from prismatic forms. This was not only to preclude the difficulty of extracting the relevant information for other geometric forms, eg pyramids but also is in keeping with the implicit limitations provided for in the Spacecraft 2 project. In practice a few pupils did include additional forms, but in these exceptional cases the pupils had previously demonstrated their ability in practical descriptive geometry by producing exceptional examples of Spacecraft 2 work.

It was not possible to produce a pro forma for prisms with an equivalent degree of utility as the pro forma for cuboids, as right prisms are defined not only by their thickness but also by the shape of the 'base' faces, and these vary. Nevertheless, a pro forma is necessary, to provide an orderly record for the data. Apart from the individual identification of a piece of work it is obviously essential that data is set out simply and clearly. It is amazing how untidy some pupils are with their written and numerical work, there are not many instances at school where it is really important for the pupil to write clearly and make sure that numerical work is correct. The results of a mistake in preparing data for computer-generated design however, are displayed in the resulting plot for all to see. This use of numerical information, is therefore, of additional value to that which may be placed on the computer graphics and spatial visualisation aspects of the work if it provides the pupil with some insight into the importance of unambiguous data.

In addition to mistakes produced by poorly prepared data pupils may also extract the wrong data, and or, produce an incorrect drawing. Even when the data is correct the person entering data into the computer may make mistakes. Pupils are usually requested to ask for work to be checked initially to see whether they understand what they are supposed to do. When the work is handed in for input to the computer a part of the data is selected for checking, this helps to minimise errors whilst taking less time than making a complete check, which would be undesirable as the pupil might not be so careful if he or she knows that work will be thoroughly checked.

Appendix 3 contains examples of several spacecraft that were produced mainly by third-years. Some examples are by second-years, these were produced in the technical graphics club.

9.3.3 INDIVIDUAL WORK

In addition to group project work several pupils produced a variety of computer-generated designs. These designs were produced in either the technical graphics club or in technical graphics lessons. To a certain extent work produced in the club was also continued within lesson time. Individual work preceded and contributed to the development of group projects, which in turn led to further, deeper involvment in individual work. The work is discussed below.

9.3.3.1 THE TECHNICAL GRAPHICS CLUB SETTING

Computer aided design was first offered to pupils in the technical graphics club. Most of the work was based on spacecraft, robots, and buildings. Cars design although popular had to be excluded because the satisfactory computer generation of wheels (cylinders) would have consumed too much memory and would have taken too long to plot with complete hidden-line removal.

The club was open to all pupils and operated after school once a week, although in practice some work was carried out during lunchtimes. A poster was produced to advertise the club. See Appendix 3. The additional attraction of an opportunity to engage in computer aided design increased the membership of the club, although this never rose above ten pupils. It has to be remembered that the work was carried out without the pupils experiencing running programs and seeing the plotter at work. This detracted from the appeal of the work.

It was very rare for examination age pupils to come to the club for advice on technical graphics. Pupils came to the club to engage in computer aided design, most of the pupils were from years 1 to 3. The main exception was a sixth former (Terence Watson) who was very keen on drawing and computer-generated design in particular. The pupils who attended the club tended to be of above average ability. Several opted for technical graphics in both the third and fourth year, and the number of pupils taking the subject increased. Although a survey of pupil's reasons for opting for graphics was not undertaken, pupils were questioned informally and the possibility of design work involving the computer was mentioned by many pupils as an attraction.

The work produced in the technical graphics club had an effect on lessons as examples were put on the wall and aroused the interest of many pupils. Several pupils asked if they could do similar work in lesson time, as for one reason or another they were unable to attend the club. Interest was further stimulated by club members who were allowed to continue with computer graphics work in lesson time. This was quite reasonable as the computer graphics work being based on the use of grid papers naturally blended in with the more conventional lesson material. Instructional material was developed to enable work to be undertaken in the classroom, this is discussed below.

9.3.3.2 THE CLASSROOM SETTING

The introduction of computer-generated design work in lesson time was facilitated by the manner in which topics were attempted by pupils, that is by progression by means of the 'worksheets' mentioned above (Section 9.1). The computer project worksheets were simply fitted in to the course. Inevitably this means that only the more able pupils attempt the computer work first. This makes the teacher's task easier, in addition the work produced by the more able pupils is seen by other pupils, who ask questions and so are partly conversant with the project requirements before they in turn start work. The least able pupils although having an equal opportunity to tackle the computer project work did not in fact manage to complete the essential preliminary work. This is a more acceptable situation than attempting to offer the whole group the project at the same time, with the inevitable result of some pupils falling behind and becoming dispirited.

Since the computer work was not explicitly part of the course for third-years, there was no need to evolve methods to overcome the difficulties that the least able pupils would have in tackling the project. However, the possible incorporation of computer aided design work into technical graphics courses is now supported by syllabuses. Although centres are not expected to have software capable of generating three-dimensional design concepts. See Appendix 1 for a specimen GCSE syllabus.

At present, given the PICASO system and the programs developed by means of this study only lack of suitable equipment in the classroom precludes the inclusion of computer aided design into school courses. It is therefore, important to discuss the rather limited exploratory work that was carried out to establish suitable means to enable every pupil in a typical mixed ability group to participate in computer-generated graphics work.

During the period of the research an opportunity arose to try computer aided design with children who were somewhat behind in basic subjects. They either had difficulty with English or maths or both. Children who have been identified as being in need of remedial help are withdrawn from their tutor groups during English and, or maths lessons and are taught by a remedial teacher or other member of staff attached for part of his or her timetable to compensatory education.

The researcher had a group for maths. In addition to arithmetic and work based on Modular Maths the Head of Compensatory Education agreed to some work being carried out on computer graphics. The rationale being that the children needed not only help with their maths but also to regain some confidence in their ability to learn. It was hoped that the computer graphics work would help the pupils to appreciate the importance of working carefully and the link between number work and drawing, and they would be able to talk about the work with other children.

The work involved coordinate work in two dimensions, data was used to generate computer drawings as pattern elements. The computer produced patterns were used as material to colour in various ways. One pupil who was particularly good at drawing was selected to tackle the City Block project. As anticipated, the pupil had little difficulty with the extension of XY to XYZ coordinates. Her design consists of a large number of cuboids and is one of the most interesting designs produced by the younger pupils.

Although the extraction of XYZ coordinate data from the drawing might seem to be a difficult task, difficulties usually arose because pupils did not have sufficient ability to complete a satisfactory three-dimensional design rather than with the coordinate aspect of the work.

Returning to the possible difficulties that might arise in offering similar work to a mixed ability group it would seem that provided the pupils are given a carefully designed form to record the data and are encouraged to work in a methodical manner they should be able to extract the relevant data.

Obviously there is a link between coordinate work in three-dimensions and a pupil's spatial ability, but it is possible to apply the analytical approach without recourse to visualising. Coordinate geometry provides a guaranteed method to solve certain spatial problems, whereas traditional pure geometry is not only dependent on intuition but often involves complex constructions. (KLINE, 1972 p 201) The analytic approach provides a means to think about and discuss technical drawings which is completly unambiguous.

Where it is necessary to mobilise the pupil's spatial ability to visualise the design the coordinate approach enables a simpler framework to be imagined to which the design may be related. The technical graphics teacher has merely to remind pupils of the notion of coordinates as they should have attained the concept of a coordinate pair either as XY or as map coordinates from their mathematical and geographical studies respectively.

Extension to three coordinates is not difficult especially as has been mentioned above the Z-dimension is referred to depth (Section 6.4.1). Difficulties arise if the pupil is also obliged, without close supervision, to add labelled axes. This is because the pupil may not have a good grasp of the significance of the alternative arrangements for the selected views.

Notwithstanding the desirability of ensuring that pupils are familiar with arranging views it seems best to either supply pupils with grid paper that has labelled axes (see sample used for the City Block project in Appendix 2) or for the teacher to add the appropriate axes.

Whilst technical graphics teachers who have a mathematics training are rare, many of the younger teachers should have little difficulty incorporating the use of XYZ coordinates into their teaching, and, as has been suggested in Chapter 10 may find that certain fundamental concepts are easier to teach. Older teachers may find the use of coordinate frameworks, like teaching in third-angle projection, tedious.

9.3.3.3 THE POLYTECHNIC SETTING

In addition to work with children with learning difficulties it was also possible for a time to offer sixth form pupils computer aided design as part of their extension studies course in the area of technical graphics.

In practice only a few pupils opted for technical graphics and apart from one pupil who was studying CDT for an A level GCE the other pupils dropped out gradually, they decided that their time would be better spent on private study for their examination subjects. Although it would have been possible to set up computer graphics sessions in the polytechnic, pupils would have had to make their own way there. This would have caused a problem as although the polytechnic was not geographically far away, it is difficult to get to using public transport. There was also possible clashes with polytechnic students wanting to use facilities, and courses laid on for external students.

Bearing in mind these difficulties, pupils were not promised that computer-generated graphics would be a principal part of the course. Since so many pupils dropped out it was relatively easy to offer computer-generated graphics to the remaining pupils as they could be taken by private car. Ultimately only one pupil remained. In the advent that facilities were not available, as occasionally occured, although disappointing at least it was easy to return to school. In two instances when it was not possible to use terminals, time was spent in the polytechnic's library, and visiting departments, which was in itself a valuable experience.

The school might have axed the option as only one pupil was regularly attending but the time was also used to process students work from other groups, for which no leave of absence had been granted, owing to staff shortages in CDT. The pupil concerned was also very keen to continue with the work, which was quite unique at that time. The new school had just been formed from amalgamating Creighton with Alexandra Park school, staff were plentiful due to the amalgamation and consequently bearing in mind the various factors, it was not considered unreasonable to continue the course, which consisted of one lesson a week, even with only one student.

This pupil who for his efforts deserves to be named: Clive Carter, completed several designs including a number of spacecraft. The design work for 'Saberay' included work on the interior of the command centre. Although the work was completed for entry to the computer the joining of the interior of the craft with the superstructure was not plotted because at that time PICASO did not have complete hidden-line removal and AUTOPROD could not handle the massive amount of data that was generated. This was disappointing as it would have been very interesting to see perspective views of the interior of the craft, particularly as the project was to have included objects placed outside the command centre windows, which would have been visible through the craft's windows or hatches.

work was also carried out for illustrating one of the pupil's CDT projects - the Hydra Link. This work involved generating a model of the Link piece.

Clive Carter was the only pupil to use the computer directly. Although he had a micro-computer (a Sinclair Spectrum) and would therefore, not be unduly impressed with using a computer he was fascinated by the output of the PRIME mini-computer, even though this was displayed as a monochrome image at the terminal. He was quite unexpectedly content to type in his data and run programs. It was anticipated that there would be some disappointment due to lack of colour, and the amount of effort required to enter data. But this did not prove to be the case, perhaps a pupil of more average ability would be less patient, as there is often a considerable amount of work to do to enter data.

Data entry was facilitated by tab sets, and in keeping with experience gained through running PICASO, programs or subroutines that were written to read data from disk files were restricted to entering each discrete item of data, eg, an XYZ coordinate of a point as one entry, equivalent to one line on the printout or one punched card. The sample printout shows how the orderly spacing of the data helps to facilitate not only data entry but also data checking. Pupils were taught how to identify and insert amendments to rectify errors, so as to minimise the teachers work.

In addition to using VDU terminals at the polytechnic Clive Carter was also shown how to use the plotter and subsequently operated it to plot his work and also work for other pupils. It was quite evident that Clive gained a considerable amount of satisfaction from using the equipment.

CHAPTER 10

EVALUATION AND CONCLUSION

10.1 INTRODUCTION

This case study is unusual in that the development of the programs and associated learning materials and the use of the materials in school was entirely under the direction of the investigator.

No deliberate attempt was made to involve other teachers. This was partly due to the extra difficulties, and partly due to the reluctance of teachers to engage in activities that would inevitably extend beyond the length of the normal school day, made worse by union sanctioned campaigns of industrial action.

An additional factor was the reorganisation of education within Haringey resulting in the amalgamation of Creighton and Alexandra Park schools. The amalgamation meant that teachers were obliged to teach in both Alexandra Park and Creighton sites and this meant for some staff teaching in three distinct places, as the Creighton site is divided into two Wings.

Even without the above difficulties the rapid introduction of the new courses in graphical communication and CDT to replace technical drawing, woodwork, metalwork, and engineering, coupled with the introduction of 16+ examinations and their replacement with GCSE meant that staff were, and still are, continually engaged in curriculum development. It is not suprising that such were the pressures on staff that only one teacher expressed enough interest to suggest that he accompany the author to the polytechnic to see for himself how the drawings were produced.

Whilst it might be thought that the disruptive effects of reorganisation due to falling rolls and curriculum development are but a passing phase, it could be argued that disruption has been virtually continual since the Second World War. There have been changes in the school leaving age in the late forties and middle fifties, difficulties due to the rapid increase in the birth rate after the war, changes brought about by the introduction of comprehensive education, the introduction of CSE, and at present the prospect of the introduction of widespread testing according to national criteria in basic subjects like English and Mathematics (The National Curriculum, Education Digest, 31st July 1987). Ultimate replacement of the GCE A Level examinations are also under consideration. The pace of technological change has also increased. Secondary school rolls are still falling with consequent insecurity for staff, whilst primary education requires more staff.

It would be quite reasonable to argue that pressure on staff is not likely to ease as there is little prospect of a period of stability during the next decade. Bearing in mind that in addition to the stress likely to be generated by instability, most staff have various responsibilities both departmental and pastoral which are demanding both of time and effort. It is, therefore, most unlikely that teachers will make use of facilities for computer aided design unless they are easy to use, that do not increase their work load unduly, and that are not situated apart from the school campus. Except, possibly, if there are benefits which outweigh the extra work. An additional unfavourable factor is that very few teachers are familiar with computers and this situation will not really improve until would-be teachers in the present generation of school students become teachers.

10.2 THE PROBLEM OF EVALUATION

10.2.1 INTRODUCTION

An evaluation of this investigation needs to take account of the fact that programs for producing instructional design in the area of practical descriptive geometry did not exist prior to this investigation, and that research had not been undertaken on the type of programs that are required for teaching practical descriptive geometry.

Apart from the mathematical analysis of what descriptive geometry is, very little research has been undertaken on the nature of the subject taking into account the psychological factors, especially of children. Chapters 3, 4, and 5, attempt to shed light on this important but neglected area of what is really an element of mathematical education.

Programs were written and the development has been substantially completed except for some problems which are discussed below.

Although an appropriate range of instructional materials could not be entirely designed by means of computer-generated graphics, some work was undertaken using computer-generated materials. The pupils' design work provides evidence that the programs and instructional material can be used to realise individual designs.

Given that the problems mentioned below can be resolved so that it will be possible to produce instructional material for all of the essential topics of three-dimensional descriptive geometry it will then be possible to undertake a formal evaluation, ie by setting up experiments, to find out whether the benefits of using computer-generated graphics and instructional material are worthwhile. Worthwhile in the sense that schools be recommended to buy suitable computers, ancilliary equipment, and software.

For the instructional designer, provided it is known exactly what illustrative material he or she needs to produce it is obvious that the facilities that have been developed using PICASO do save considerable time, even though work may have to be finished by using PICASO EDIT or a combination of all or some of the following: tracing, colouring, shading, labelling, and retouching.

The following commentary discusses the difficulties and suggests changes that might be made to gain more reliable information about students progress.

10.2.2 EVALUATING PUPILS' LEARNING

For a time the investigator taught the same course to examination groups in both Alexandra Park and Creighton sites. This provided an opportunity to compare the performance of students that had experience of computer- aided design and instructional material based on the use of the XYZ coordinate reference framework with those that did not. Both groups of pupils seemed equally motivated, attendances were similar, and examination results were also similar. But the groups that had experience of computer-aided design and the XYZ system seemed to have a better grasp of spatial structures.

This is a tentative observation and would need to be supported by a well designed experiment, this was not feasible for a number of reasons. Apart from the fact that the material under development was not sufficient to enable a complete course to be designed using computer-generated illustration, the disruption caused by the reorganisation of secondary education in Haringey precluded the necessary control over teaching groups which would be necessary.

The CDT department had staff joining and leaving, and the department itself was a product of amalgamation. The Alexandra Park staff component of the department was still running courses for woodwork, metalwork, technical drawing, and engineering science; whilst the Creighton School staff were running CDT and graphical communication courses. Individual staff in both schools were teaching technical graphics in different ways according to their experience and course content. In some cases they were teaching students they had not taught previously.

Even if suitable materials were available it would not necessarily be significant to compare public examination results in any of the contemporary syllabuses as none provide separate marks for the descriptive geometry content. Unless a pupil achieves a grade A, there is no guarantee that the pupil has achieved some degree of mastery of the basic concepts of descriptive geometry, as the wide ranging content of the various examination syllabuses provide opportunities for students who are weak in spatial understanding and geometry to gain valuable marks elsewhere in the paper. Yet the aims of the various syllabuses stress the primary importance of three-dimensional visualisation and skills that are associated with the acquisition of such abilities. The value of the public examination as a measure of a person's ability to comprehend, generate, and represent three-dimensional spatial structures and objects is, therefore, unreliable.

Whilst the examination papers provide weak students with the means to evade spatial problems the amount of time available to cover the geometrical part of the syllabus and everthing else is barely sufficient. It follows from the above arguments that even if the researchers' students had gained significantly in understanding of three-dimensional spatial relationships, this advantage might not be evident in examination results.

Specially prepared tests will need to be designed and because of the new method of instruction, introduced by the author, involving the use of elementary three-dimensional coordinate geometry it will be difficult to compare the performance of other children who have been taught using conventional methods of instruction with the author's group or groups, as the anticipated benefits may be due more to the coordinate approach than to the computer-generated material.

In reference to examination performance it should be noted that because the investigator's pupils have been taught by means of the XYZ coordinate reference system there is a danger that the use of the XY line convention in examination papers may confuse pupils. It is therefore incumbent on the investigator to teach his pupils to consider the XY line convention as merely a general method of reference denoting the intersection of two projection planes.

Whilst the brighter pupil should be able to assimilate this additional information it is doubtful that other pupils will. It is possible that the pupil's performance may suffer as a consequence. This is most unfortunate as it is argued above (Section 6.4.1) that the use of the XYZ system is an important means to communicate the relationship between corners, edges, contours, and surfaces of objects and the vertical and horizontal spatial directions.

It is also disheartening to contemplate experimental research when teachers have little more information than the age and gender of their pupils; as it is necessary to compare the control groups with groups which are closely matched as regards, intelligence, social status, and other factors. The proposed regular testing of children's ability in mathematics and English in the UK will provide valuable information with which to manage the variables which are involved, particularly if a spatial ability test is included.

If the GCSE examinations in technical graphics are to have maximum value to the pupil, employer, teacher and further education the possibility of having a grade for the three components: technical drawing ability, three-dimensional spatial understanding, and representation and possibly other components should be considered. This does not imply that examination papers need to be split into sections as it would be possible to ascribe marks from each question to each of the components.

Furthermore, apart from the periodic publication of subject reports by the examination boards which provide some feedback on the response to a paper, there is no other information, other than the examination result which may shed light on the performance of the student, question by question. This is remarkable, not only in terms of the individual but also in terms of national performance. At present the only other feedback system is Her Majesty's Inspectorate, and this is undermanned and only provides the subjective aspect.

With the mass storage techniques that the computer can provide, it should be possible for the DES and authorised researchers to gain access to statistics on any individual's performance on any item in an examination paper. This would provide a means to monitor the response of students to spatial problems and other content, with a view to making improvements in teaching and resources, and in the design of examination syllabuses and papers.

10.3 THE PROGRAMS

10.3.1 INTRODUCTION

Prior to the development of the programs by the researcher it would have been completely uneconomic to use existing software to produce illustrations of a three-dimensional nature for use in school and for student design as the bulk of the available software had been designed for industrial use in conjunction with special workstations intended to be used by a specially trained operative. This observation is further supported by investigation, very little evidence could be found that any other researcher had produced illustration for use in teaching practical descriptive geometry and for student design work.

PICASO provides the means to write programs for either a specific purpose or for general use in both two and three-dimensional design. Up until the author undertook this study there were no programs written in PICASO that could be used by a technical graphics teacher to produce three-dimensional type illustration, or offer computer-aided design to students.

It is important to stress that the development of the programs could not have been undertaken without PICASO. The research adds one more application to those mentioned by Vince (1975, p90) namely: to produce both illustration for didactic purposes and facilitate the writing of programs to enable school students to engage in computer-aided design work.

10.3.2 PROBLEMS

A number of problems arose during the development of the programs. These have been mentioned in Chapter 8, and are summarised below. The problem of complete hidden-line removal was economically solved by Dr. Vince, certain other problems remain.

First and of great importance is the resolution of problems that arose in the generation of projections of a three-dimensional structure or object onto a plane surface that itself exists in a three-dimensional conceptual space. This facility is necessary to enable illustration to be prepared for teaching the principles of projection and to enable the pupil to explore what an object looks like from various directions. The resolution of this problem would enable not only main views but also 1st and 2nd auxiliary views to be generated as three-dimensional data structures that could be viewed from any direction just as if the user were viewing a real three-dimensional model.

The computer-generated equivalent to a three-dimensional model has a number of advantages over a physical model. A variety of different three-dimensional PICASO objects could be selected as subject matter, including students own designs. The latter option is important as pupils seem to have a much better understanding of the spatial elements of their own designs, and have more interest in them. To each of these models additional elements may be added, such as conventional line types (discussed below), projection planes, projection elements (lines, notation, arrows etc) and views of the object. Another important advantage is the possible degree to which the teacher may control factors which affect the students perception by stimulating attention. These factors can be derived from the variables which are associated with representation: the position from which the computer-generated model may be viewed, the addition of a three-dimensional model of a robot or human (as a model of the viewer) and other reference elements, and colour and shading.

The second important problem arises out of providing a facility to close a PICASO type object with a surface. This facility is needed when a cutting plane is used to divide an object in order to make a new object, or to see the inside of an object. The latter is a common operation in engineering and constructional drawing. This problem is associated with the setup of PICASO type objects as shells, surface configurations rather than solids. It is as natural to think of constructing three-dimensional objects either as aggregates of primitive solids achieved by joining, or by taking pieces away from a simpler solid to form a more complex solid. Therefore it would be desirable to develop PICASO routines to facilitate the writing of programs to enable the designer to use either or both methods of creation.

The final problem involves generating lines. The lines used in technical graphics can be divided into two classes: lines which represent the object: visible edges and contour lines, and lines which are symbolic in nature: invisible edges, centre lines, reference plane axes, lines of symmetry, limits of motion, cutting plane lines, hatching or section lines, adjacent parts, short and long break lines, projection or extension lines. Appendix 1 contains extracts from BS 308: Part 1: 1972 which refer to the various types of line in common use.

At present these lines can only be added to an illustration using the PICASO EDIT facility, which enables images to be edited in various ways. Whilst EDIT is a valuable facility the additions that are made to an image are two-dimensional. There is a need to produce lines which are images of three-dimensional PICASO objects. The facility is probably essential if the problem of generating accurate views of PICASO objects as objects which are part of the same three-dimensional data structure as the viewed object is to be resolved, and since students have to learn why the various lines are necessary a three-dimensional view which includes lines would be invaluable, not only to aid visualisation but also to produce sectional views of students' designs and facilitate the production of didactic illustration.

What is drawn is commonly referred to as two-dimensional work, but what is seen and can be touched is three-dimensional. Lines on paper or any other surface are physical objects that may be analysed as to the type of deposit used, eg. pencil, ink, chalk, etc. If it is necessary to generate a line as part of an object or to facilitate instruction then the line must be equivalent to a three-dimensional model. A projection line for instance, may be thought of as a fine black thread stretched between two points, as a PICASO type object it may be thought of as a very thin prism or cylinder. The projection of an image onto a projection plane may be thought of as a glass-like panel on which the image is made visible by placing stretched black thread wherever there is a straight line, and a series of very short stretched lines to follow a curve. Each piece of thread may be realised as a PICASO object by generating a prism or cylinder. The collection of these PICASO objects must be arranged to lie coplanar with the glass-like panel, which itself can be synthesised. This method would enable any type of line to be generated, and therefore, enable any type of technical drawing to be produced as a view from a three-dimensional PICASO object. Work on this problem had to deferred as the amount of data generated to synthesise anything except very simple images is considerable.

Technological developments are making the storage and retrieval of massive amounts of data relatively insignificant. Similarly processing speeds have improved. The processing time for complete hidden-line removal is still considerable, especially with large data structures, but not prohibitive. Restrictions may apply to hidden-line and other routines which may have maximum parameters on the amount of data that can be processed. Provided these can be overcome it is now feasible for work to be carried out on the generation of three-dimensional line modelling of views and symbolic-type lines mentioned above.

The retrieval of line segments from a projection generated by PICASO routines in order to synthesise a three-dimensional model of the view is not a simple task. A special routine will have to be devised. LNE3D may be used to generate the line segments once they have been extracted.

10.4 PROGRAMS REQUIRED

Although the research and development extended over a period, including preliminary work, of several years there has been little change in the availablity of software of the three-dimensional CAD type for use by teachers. Programs exist to generate orthographic views, and perspective or isometric views; but as the user is expected to be a trained operative there has been no need to consider software that can be used by the teacher to generate illustration or to enable the student to gain greater understanding of spatial configurations.

In a letter from the DES to all Chief Education Officers (DES, 21st July 1987 p.2) it is recommended that future computer systems in school should provide compatibility with commercial software and systems in this and other countries. The reasons for making this recommendation are twofold, first: generic business software is becoming increasingly important in schools, second: 'all the evidence suggests that alone, the UK market for educational software is, in the main, too small to be economically viable, and therefore that multi-national collaboration on software development will continue to grow.' Apart from the implication that the portability of software will be of major importance, it is evident that the author's development would not normally have been undertaken, as it would have been uneconomic and indeed the PICASO SYSTEM would not have been developed except by research in an educational institution. PICASO and programs which make use of PICASO are portable as PICASO is written in FORTRAN.

In addition to the various programs that have been developed and discussed in Chapter 8 there are a few programs which still need to be developed and which were not, primarily because of the difficulties discussed above.

A program is required for generating a three-dimensional model of the projection setup. This program would provide the means to generate views of any PICASO type object onto picture planes. Although some work was undertaken on the projection of auxiliary views (see Appendix 4) the problem of determining methods to facilitate the generation of 1st and 2nd auxiliary views would have to be developed. This model would enable the projection setup to be viewed from any direction in order to clarify the relationship between the object and its various projections. It is the essential facility, providing the instructional designer with the tool to generate any spatial structure as a model which may be viewed from any desired position and may be generated to any scale. The possible inclusion of any particular objects including model human figures provides the means to generate models of greater interest and utility than would be feasible using traditional methods. The extent to which such computer-generated models could help the student to come to an understanding of the fundamental concepts of descriptive geometry depends on the model generated and the way in which the model is used. It would be desirable to design a selection of scenarios which could be used by the teacher as well as providing the means for the teacher to design his or her own models.

Programs are also required for generating the different types of three-dimensional lines which may need to be added to PICASO type objects, eg. centre lines may be added to objects that have cylindrical parts. This group of programs or subroutines should include facilities to generate an alphanumeric set of three-dimensional characters for adding to objects as well.

10.5 DOCUMENTATION

In order for the programs that have been developed to be used it will be necessary to prepare documentation. The content of the manual for using the author's programs can only be precisely defined on completion of the development.

Documentation will logically be based on a general introduction to PICASO programming and a description of the extent and function of the programs that have been developed. It will also be necessary to provide a guide to running the programs on the particular computer which is to be used, and how to operate the various peripheral devices, such as a plotter. Other material will need to be provided if PICASO EDIT and other programs are to be used.

10.6 COMPUTER REQUIREMENT

The primary requirement is that the computer must be capable of running FORTRAN and have sufficient memory to hold PICASO and the author's development. The speed of the machine and its RAM size will limit what sort of work can be carried out. It will be desirable for the computer to conform to the recommendations made above (DES letter to CEO's) so that it may be used for other purposes. The new type of micro-computers based on RISC technology, the Intel 80386 micro-processor, or the TRANSPUTER would provide speed and facilities for implementing the development in a school environment.

Financial considerations will determine to some extent what type of computer can be purchased. But it should be noted that several thousand pounds may be spent on a reconditioned lathe for workshop use that is only in use for a few hours a week by older students, whereas the computer may be used from the first-year upwards and may be used for work other than CAD. The option to purchase a powerful micro-computer although more expensive may be cost effective in that it could be used for routine administration throughout the school and may save its own cost within a year or two.

10.7 SUMMARY AND RECOMMENDATIONS

10.7.1 SUMMARY

The author would like to be able to continue to use the programs developed by means of PICASO. Primarily because, notwithstanding the problems which remain to be solved, it has been useful as a means to generate illustration which can be used to support the author's teaching.

The facility is structured to enable design work to be translated into data by means of squared grid paper and it is also possible to use isometric grid paper (examples in Appendix 4) this is more convenient than sitting at a workstation. It is also probably faster, as the design concept probably has to be drawn on paper before it is drawn on the screen of the workstation.

The interactive computer-aided drafting and solid modelling facility afforded by a workstation type implementation may have advantages over the author's development for the independent technical illustrator engaged in work for educational publications, but this will need to be determined by further research. But care has to be taken to ensure that the software falls into the same cost group as PICASO and the author's development. There is a major problem here as industrial standard software with three-dimensional solid modelling facilities which are as advanced as that offered by PICASO and the author's development can easily cost in excess of £9,000. This is because in addition to the three-dimensional options, it is necessary to have options associated with production and cost control. Such software also requires much more RAM than PICASO and high-resolution colour monitors.

The Dutch have decided to install 10 microcomputers with computer-aided drafting software (two-dimensional only) in every Dutch secondary school A similar decision in England and Wales would require twice the number of computers. The Dutch initiative should be investigated to assess the possible advantages. Clearly one obvious advantage is the early training of Dutch students for employment. Whether there is this need for computer-aided drafting personnel is an interesting question.

PICASO has facilities which could be developed to enable computer-aided drafting to be carried out. The advantages over many commercial drafting programs are that PICASO programs are written in FORTRAN which being a compiled language runs faster than programs written in BASIC.

The other main reason for wishing to continue to use the programs developed by the author is because of the facilities which it provides for pupils to design objects. Pupils are more likely to think about the descriptive geometry involved in representation when it can be linked to their own design concepts. This interest manifests itself in increased motivation which not only eases the teacher's task but also provides an opportunity for more efficient teaching as the object designed by the pupil may be viewed in any way. Given the facility in the classroom, both the pupil and the teacher could study the design concept together. The necessity for the pupil to work in a much more methodical way according to the geometry of the various elements which the design can be sythesised from minimises errors, and where difficulties arise the teacher is better placed to resolve them.

The computer-produced drawing verifies that the student's design is correct, or that an error has been made. It is usually possible to determine which part of the object is wrong and provided the data has been entered correctly the drawing must contain an error or two. There is only one other activity that the author can think of that provides the pupil with proof that his or her design drawings are correct and that is the construction of a model by means of a development using paper or card. In many cases it is too difficult to construct a development, the pupil therefore, has no other option but to rely on the authority of the teacher to determine whether his or her design drawing is right or wrong. In this situation the pupil is more often than not, passive, puzzled, or irritated by errors; the computer-aided design work on the other hand, mobilises the pupil's interest in a more positive way.

Whilst the investigator's interests and teaching strategies are to some extent personal it cannot be argued that the computer programs may not suit other teachers as the programs provide opportunities for instructional design and pupil project work which ~~a~~ teacher could use in any way.

10.7.2 RECOMMENDATIONS

10.7.2.1 INTRODUCTION

Whilst the vocational aspects of technical graphics courses and CDT courses which include a technical graphics component are of value to the individual both in regard to future employment and in terms of his or her general education the most valuable part of such courses is the descriptive geometry component. Without a good basic understanding of the underlying geometry mistakes are bound to be made, representation of ideas by means of drawing will be inhibited, and further growth in ability to use and make drawings will be retarded. The computer can be used to assist the teacher in many ways, but the essential requirement is to enable suitable illustration to be made and to motivate the student. This investigation has resulted in a system of programs which are capable of generating illustration that would be difficult to produce by hand, and with opportunities for students to develop their own three-dimensional designs, which can be used to advantage in a number of ways both by the teacher and the student to gain a greater understanding of descriptive geometry.

It was found that the necessity to prepare data for the computer required a more mathematical approach than is usual in the preparation of technical drawings. This lead to benefits in the numerous dialogues between the teacher and the pupil as there is less likelihood of being misunderstood. A decision was made to strengthen the use of a mathematical framework and the cues which may be provided by mathematics. This decision was made because the investigator's readings in child development indicated that the establishment of an easily recogisable spatial framework would provide a means to overcome the child's difficulty with visualising spatial relationships. The easily recognisable spatial framework being the XYZ coordinate system.

Within the limitations imposed on this research study, reasonable grounds have been established for believing that savings in both time and effort may be made by means of the computer. But a considerable amount of work still needs to be undertaken.

The computer programs and the mathematics which is associated with computer graphics in the area of three-dimensional descriptive geometry together with the psychological aspects thus constitute three areas in which recommendations may be made.

10.7.2.2 COMPUTER GRAPHICS

Continuation of research

A number of possible uses of the computer were not explored and many of those that were researched were unduly restricted because the software could not be used in the investigator's own school. It is therefore recommended that further research be undertaken with facilities which are located in the classroom.

Outstanding problems

The problems which still need to be resolved to complete the development should be further investigated and solutions developed.

Documentation

Documentation should be designed and developed to enable other teachers to use the author's development and PICASO.

Surface developments

Further work should be undertaken on the descriptive geometry operation: surface development.

Complex surfaces and geometric solids

Subroutines should be developed to enable a complete library of three-dimensional objects and surfaces to be easily generated, eg. convolutes and double curved surfaces.

Computer-aided drafting

A feasibility study of the development of the PICASO EDIT program so that it can be used for computer-aided drafting should be undertaken.

Compatibility

The desirability of producing software to enable PICASO type objects to be compatible with industrial CAD applications programs should be investigated.

10.7.2.3 DESCRIPTIVE GEOMETRY

XYZ axes and standardisation

The link between computer programs to generate three-dimensional projections and the mathematical theory of descriptive geometry is analytic geometry and the key concept is the XYZ coordinate system. Owing to conceptual difficulties which the student may have with extending the notion of XY to XYZ coordinates it is recommended that the British Standards Institute reconsider the orientation of the axes.

Arranging views

One of the findings of this investigation is that students gain an understanding of orthographic views and arranging orthographic views more easily if familiar objects are represented as five views, rather than by only providing the minimum number of views. This hypothesis should be tested by further research and experiment.

Computer-generated models

The resolution of the problem of generating a three-dimensional model of an object together with projections of that object involves extra research to determine the degree of flexibility that is required. The option to generate auxiliary views as part of a model, particularly the second auxiliary view, and the facility to rotate these views into a plane equivalent to the paper is a difficult task, but one which needs to be undertaken as it will then be possible to design a complete course in descriptive geometry using computer-generated graphics.

10.7.2.4 PSYCHOLOGY

The cognitive factors involved in representation

An attempt has been made in this study to develop computer programs to enable secondary school students to gain a better understanding of practical descriptive geometry. The programs do not limit the user to a restricted range of ideas but provide opportunities for the teacher to develop illustration according to his or her ideas. However, a number of ideas have been evolved by the author which are believed to be soundly based on child development theory. In particular, the notion that a reference framework is needed to compensate for the child's difficulties with understanding the principles of projective geometry.

According to Piaget's theory it is necessary for the child to have attained to the level of formal operations to employ, without concrete aids, the principals of projective geometry to solve problems of representation. Bryant argues that it is not an inability to reason but rather the lack of ability to remember the absolute properties of things around them which hinders the child's ability to understand the world. The author believes that Bryant is probably correct and that his theory is applicable to the problem of representing objects. However, a more rigorous investigation needs to be undertaken into the cognitive factors which are involved in representation by drawing.

It is recommended that this investigation be undertaken as a natural development of the present study. The investigation could be split into two parts: a development of a theory, and experiments using computer- generated illustration and interactive three-dimensional computer graphics. It would be necessary to solve the problems referred to under computer graphics above before experimental work could be undertaken.

An early introduction to descriptive geometry

No one really knows just how much time children spend on drawing, but they do draw in nearly every subject, they study illustration, and they need to understand the meaning of words which are associated with spatial concepts. It is not known what percentage of words depend for their meaning on the user possessing certain spatial concepts. It is obvious though that money is invested both directly and indirectly in the development of graphical skills and the acquisition of spatial concepts. The author believes that the role of descriptive geometry is underrated in the development of the child's ability to draw, and that it is advisable to introduce what is in fact the science of drawing as early as possible in the child's education.

The use of grid papers in conjunction with the computer programs developed by the author provide a possible means to introduce junior school children to the science of drawing. It is therefore recommended that a study be made in a junior school.

The need for a coordinated plan of research

The author believes that there is a need for the development of a planned research program in the area of spatial education as unlike industrial research there is little incentive for many workers to undertake research. Nethertheless, the development of spatial ability is of vital importance in modern society.

The number of students, teachers and lecturers who are willing and able to undertake research in the area is small, and it is therefore most important that key areas be identified.

It would not be logical to restrict an enquiry to British research, although an attempt to encompass literature which is not in English might be too difficult.

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Retrospective Index to Theses Gt Britain & Ireland 1716-1950
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APPENDIX 1

REPRODUCTIONS/FACSIMILES FROM BOOKS AND OTHER PUBLISHED SOURCES

Table 1

GAGNE'S CLASSIFICATION OF TYPES OF LEARNING

1. signal learning:

   Definition: Pavlovian conditioning.
   Theorists: Pavlov, Watson

2. stimulus - response learning

   Definition: the formation of a single connection between a stimulus and a response.
   Theorists: Skinner, Thorndike, Hull, Spence

3. chaining - motor chains

   Definition: the connection of a sequence of motor stimulus -response behaviours.
   Theorists: Guthrie, Thorndike, Skinner

4. chaining - varbal associations

   Definition: the connection of a sequence of verbal stimulus -response behavours.
   Theorists: Osgood, Hebb, Bruner

5. discrimination learning

   Definition: learning to discriminate between highly similar stimulus imput.
   Theorists: Bruner, Ausubel, Hebb, Osgood

6. concept learning

   Definition: the opposite of discrimination it involves responding to a set of objects in terms of their similarities.
   Theorists: Hebb, Osgood, Bruner, Ausubel

7. rule learning

   Definition: a rule is an inferred capability which enables the individual to respond to a class of stimulus situations with a class of performances.
   Theorists: Bruner, Ausubel

8. problem solving

   Definition: the application of rules in the generation of higher-order rules. This is the inevitable outcome of applying rules to problems.
   Theorists: none stated.

Adapted from LEFRANCOIS (1972)

Table 2

PROCESSES OF LEARNING & THE INFLUENCE OF EXTERNAL EVENTS

Learning Phase	**Process**	**Influencing External Event**
Motivation	Expectancy	1. Communicating the goal to be achieved; or 2. Prior confirmation of expectancy through successful experience
Apprehending	Attention; Selective Perception	1. Change in stimulation to activate attention; 2. Prior perceptual learning, or 3. Added differential cues for perception
Acquisition	Coding; Storage Entry	1. Suggested schemes for coding
Retention	Storage	Not known
Recall	Retrieval	1. suggested schemes for retrieval; 2. Cues for retrieval
Generalisation	Transfer	Variety of contexts for retrieval cueing
Performance	Responding	Instances of the performance ("examples")
Feedback	Reinforcement	Informational feedback providing verification or comparison with a standard

Adapted from GAGNE (1975, p.45)

Table 3

SPECIFICATION OF OBJECTIVES FOR LEARNING: RECOMMENDED VERBS

Capability	Outcome performance verb
VERBAL INFORMATION	stating
INTELLECTUAL SKILL	
Discriminating	distinguishing
Concrete concept	indentifying
Defined concept	classifying
Rule	demonstrating
Higher-order rule	generating
COGNITIVE STRATEGY	originating
ATTITUDE	choosing
MOTOR SKILL	executing

(These verbs may be replaced but the replacement verb must have the same meaning)

Adapted from GAGNE and BRIGGS (1974, p.85)

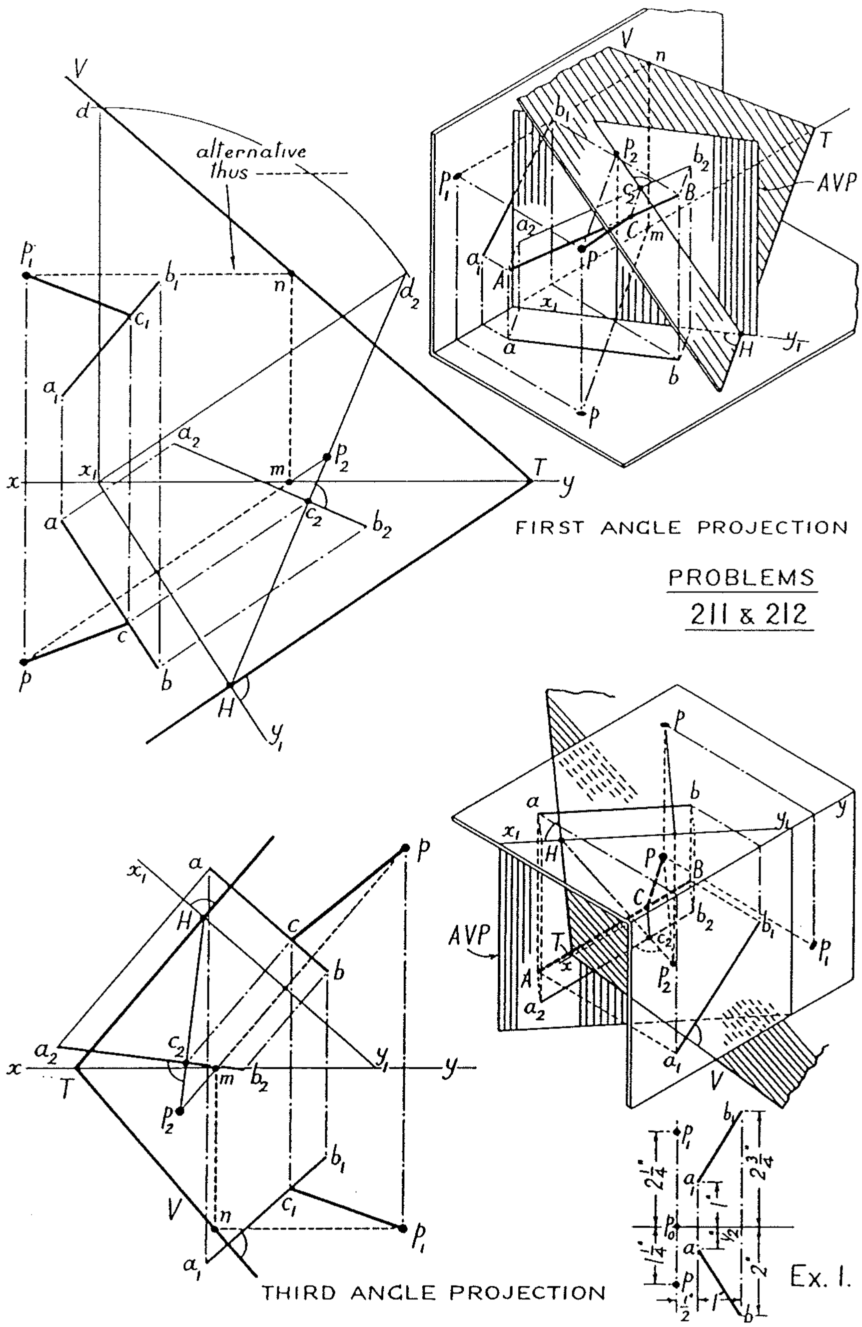


Fig. 1. Isometric scale illustrations in 1st and 3rd angle projection of related but not similar problems. The method depicted employs the trace of plane concept. ABBOTT (1963, P.215)

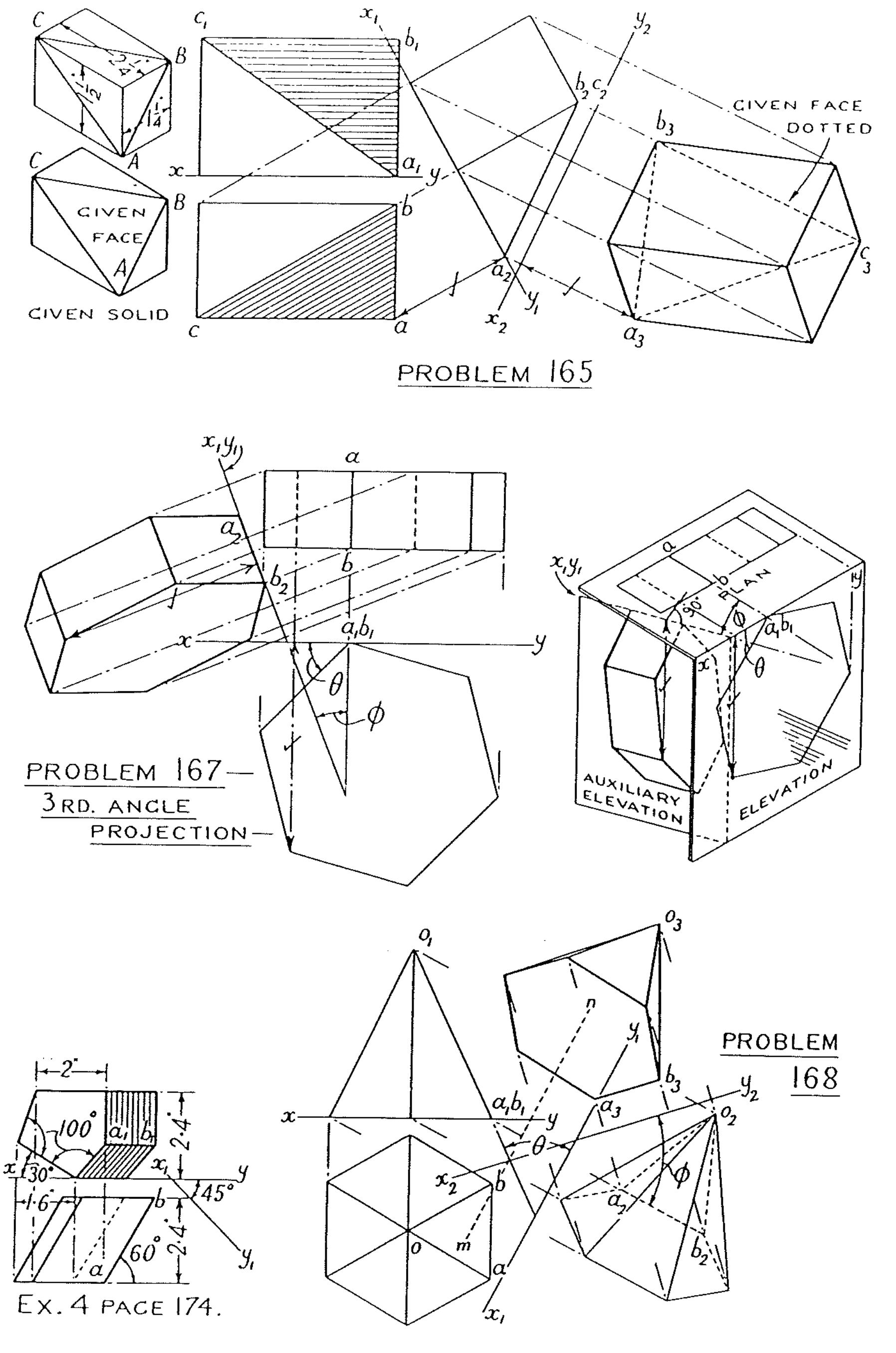
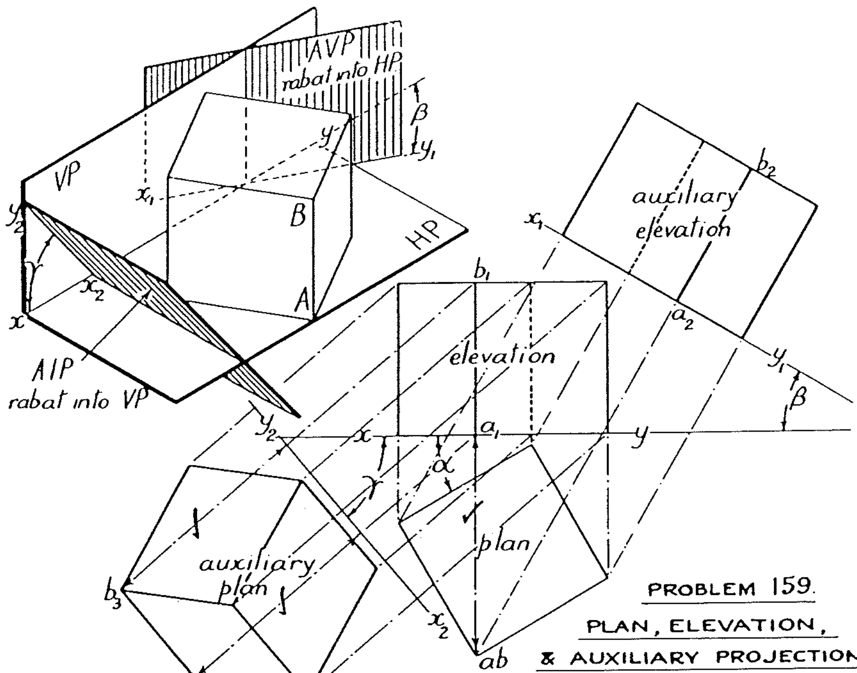
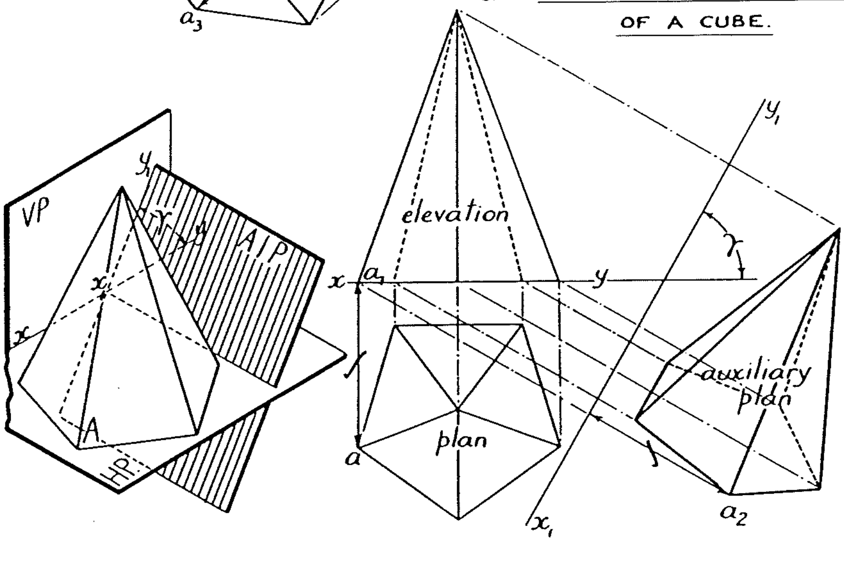


Fig. 2. Various problems which use the auxiliary view method. Problem 167 has a 3rd angle projection type isometric illustration to assist the learner. ABBOTT (1963, p.177)



PROBLEM 159.
PLAN, ELEVATION,
& AUXILIARY PROJECTIONS
OF A CUBE.



PROBLEM 160.
PLAN, ELEVATION, & AUXILIARY PROJECTION
OF A RIGHT PENTAGONAL PYRAMID.

Fig. 3. 1st angle orthographic projections and auxiliary views of solids in simple positions. ABBOTT (1963, p. 173)

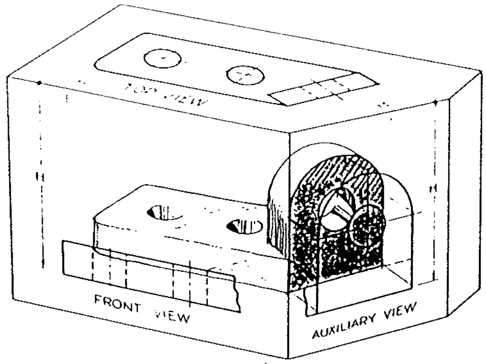


Fig. 5–81A. A pictorial showing the relationship of the projection planes used to find the true size of the inclined plane.

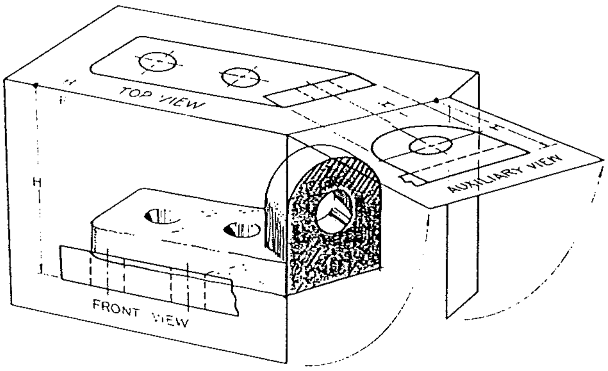


Fig. 5–81B. The projection planes are opened into a common plane to represent the plane of the drawing paper.

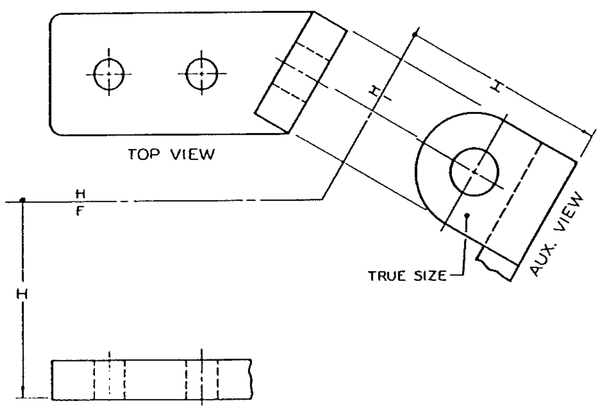


Fig. 5–81C. Construction of an auxiliary view of the object shown in Figs. 5–81A and 5–81B as it would appear on your drawing paper.

Fig. 4. The construction of an auxiliary view of an object by means of 3rd angle orthographic projection. Illustrated by means of perspective drawings. EARLE (1977, p. 120)

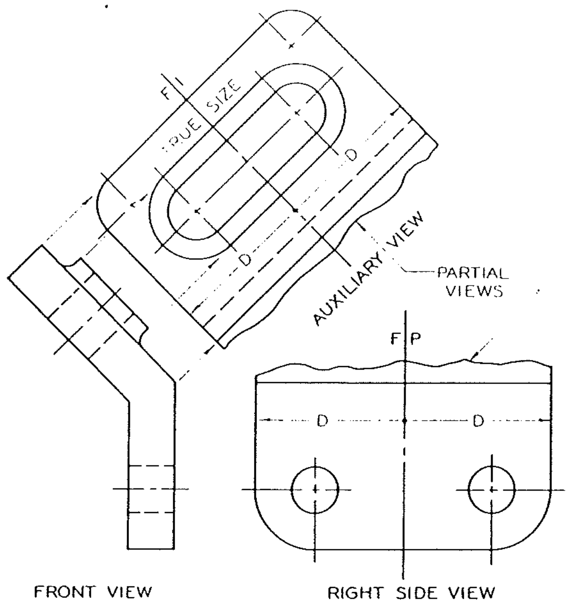


Fig. 5–83. Construction of partial auxiliary and principal views to depict an object.

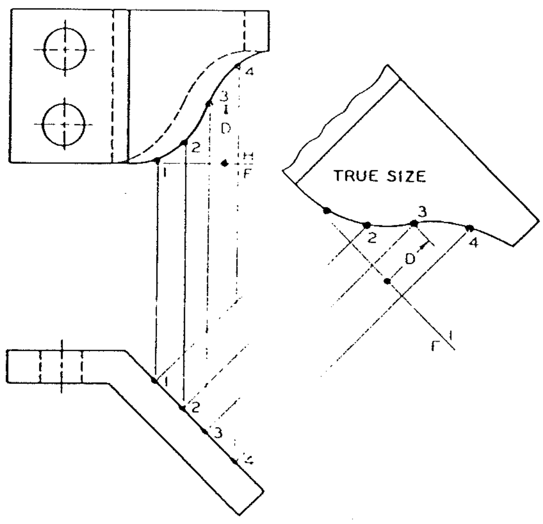


Fig. 5–85. Auxiliary view of an irregular curve.

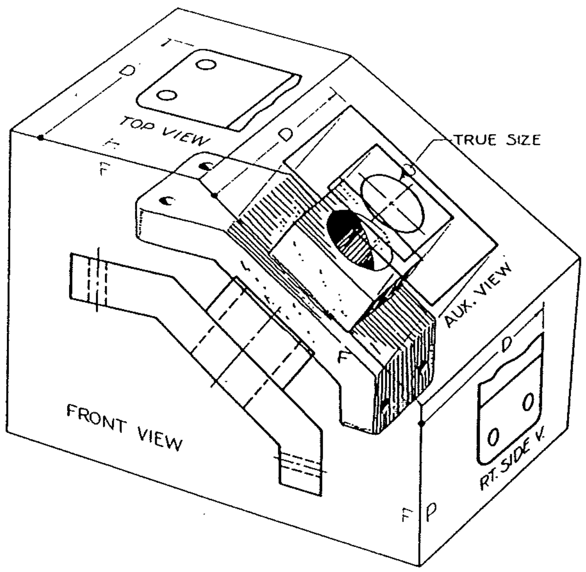


Fig. 5–84A. A pictorial showing the relationship of the projection planes used to find the true size of the inclined plane.

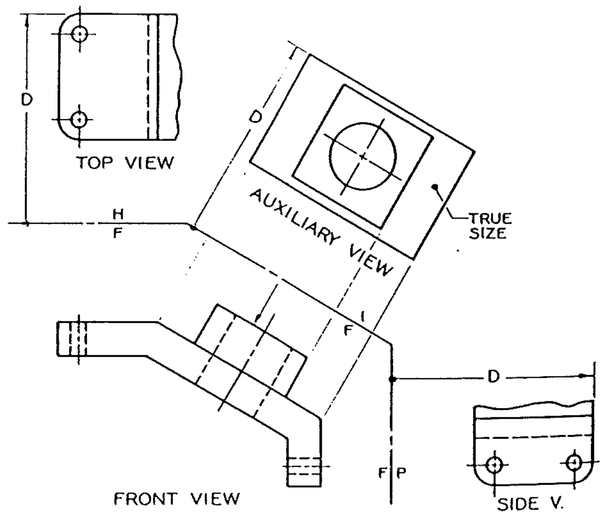


Fig. 5–84B. Construction of an auxiliary view of the object shown in Fig. 5–84A as it would appear on your drawing paper.

Fig. 5. 3rd angle projection partial principal and auxiliary views of an object. Perspective type pictorial views showing the realationship of another object to the projection planes, and a corresponding illustration of what the student's drawing should look like. EARLE (1977, p.122)

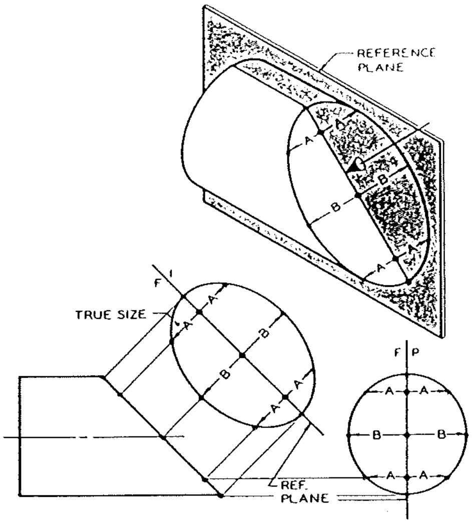


Fig. 5–86. Construction of an auxiliary view of an object requiring that a series of points be plotted. Since the object is symmetrical, the reference plane is positioned through its center.

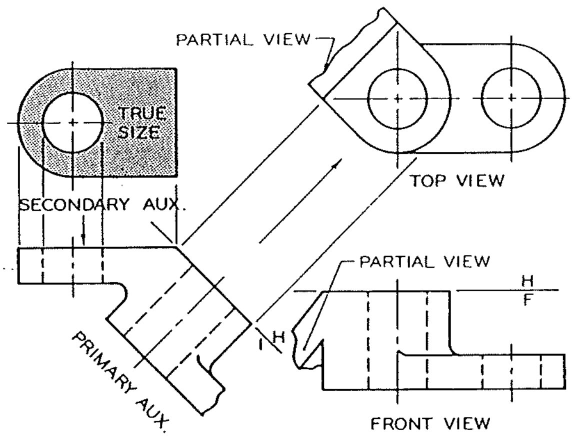


Fig. 5–87. An example of a secondary auxiliary view projected from a partial auxiliary view.

Fig. 6. Construction of an auxiliary view of a sectioned cylinder and a an accompanying pictorial illustration, which shows the use of a reference plane to assist with the construction. A second auxiliary view used to determine the true shape of a skew surface. Note that only relevant hidden lines have been shown. EARLE (1977, p.123)

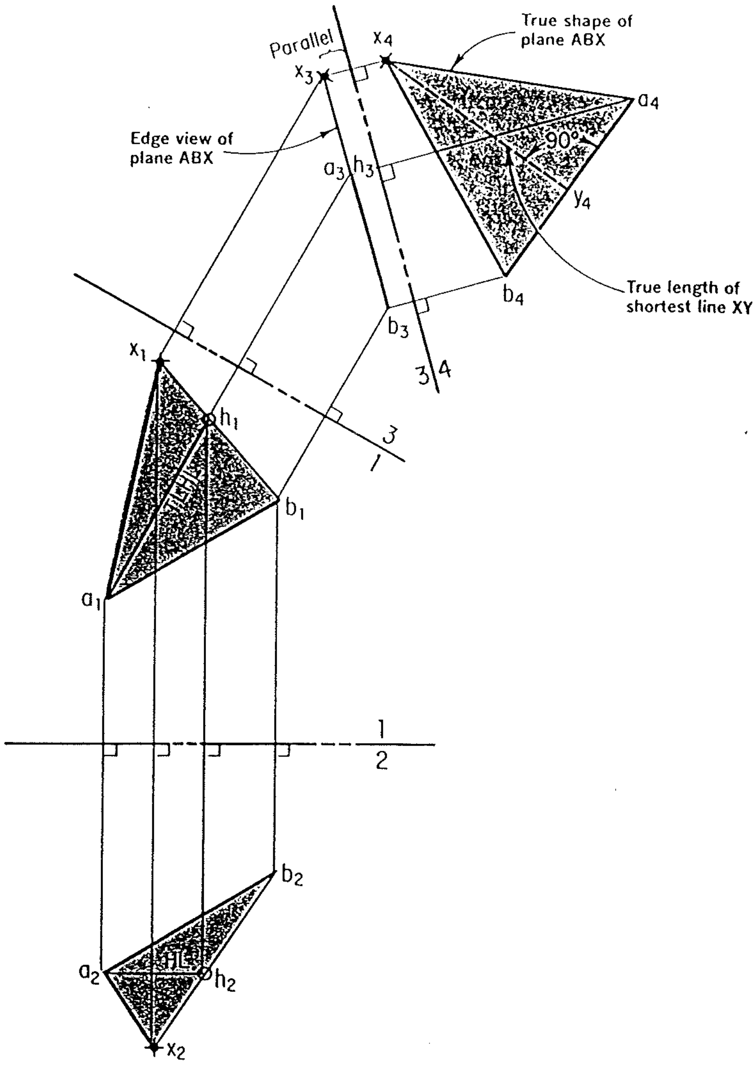


Fig. 7. 3rd angle orthographic projection utilising the auxiliary method of finding the true shape of an skew surface. SLABY (1976, p.92)

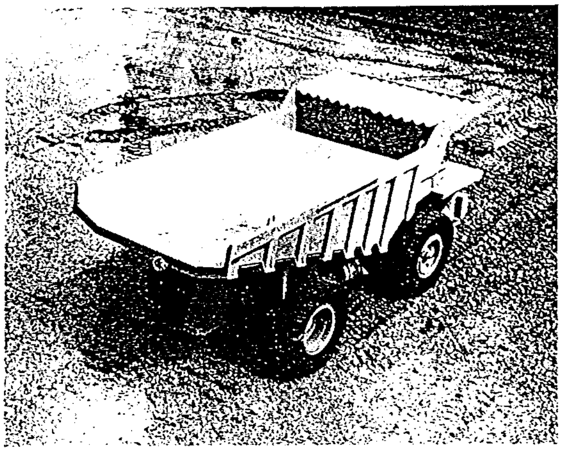


Fig. 8–6. The bed of this Model 45 Haulpak truck was designed through the use of auxiliary views to determine sizes of oblique planes. (Courtesy of LeTourneau-Westinghouse Company.)

The corners are connected to give the true-size view of the inclined surface.

The truck bed shown in Fig. 8–6 is composed of oblique planes that can be found true size by auxiliary views. Any two adjacent orthographic views of these planes can be used to find each plane true size by following the previously covered principles. It is necessary only for the planes to appear as edges in a principal view.

Fig. 8. Use of a photograph of an interesting object to link the descriptive geometry pictorial and orthographic views to the outside world. EARLE (1977, p.196)

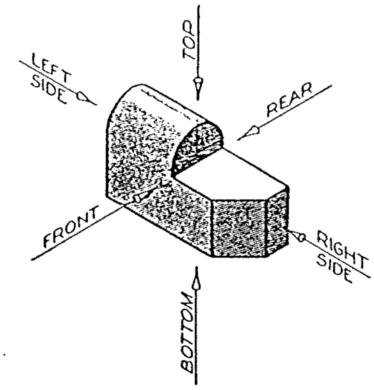


FIG. 243 The Six Directions of Sight.

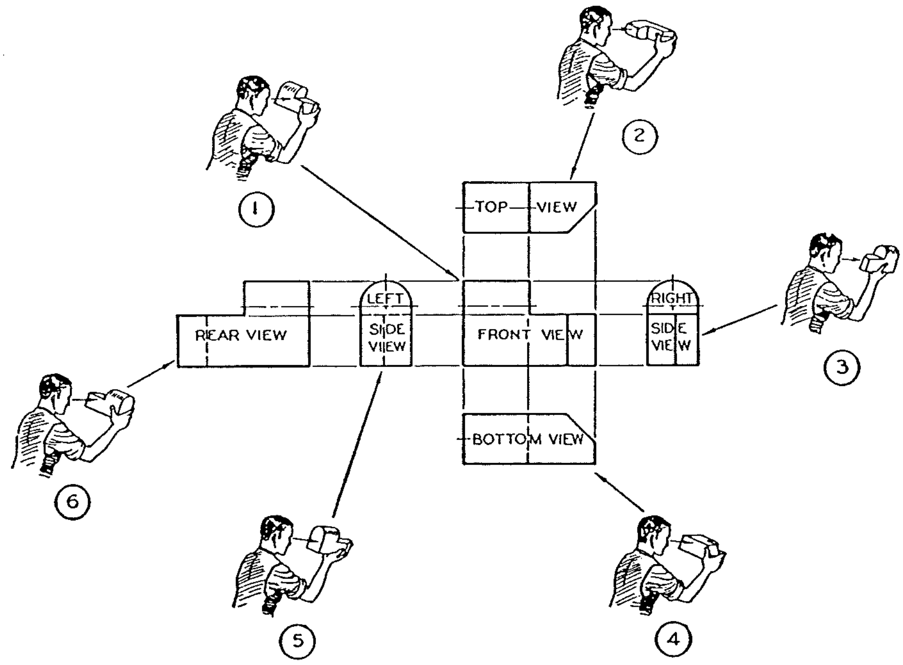


FIG. 244 Six Views of an Object.

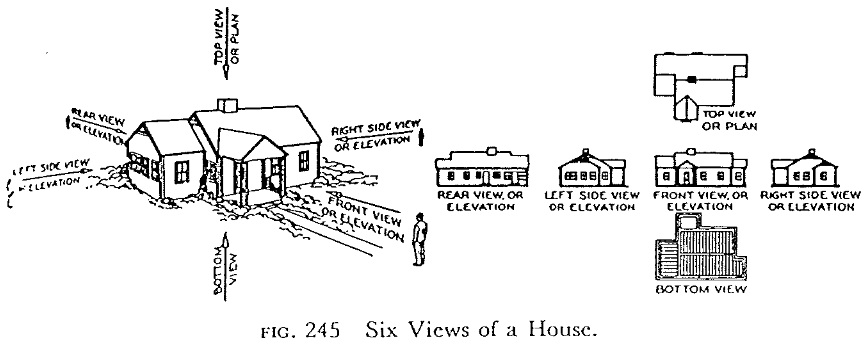


FIG. 245 Six Views of a House.

Fig. 9. Conventional 3rd angle arrangement of six views. Note the use of pictorial illustrations to clarify the spatial relationship between the viewer and the object.

GIESECKE et al (1949, p.154-156)

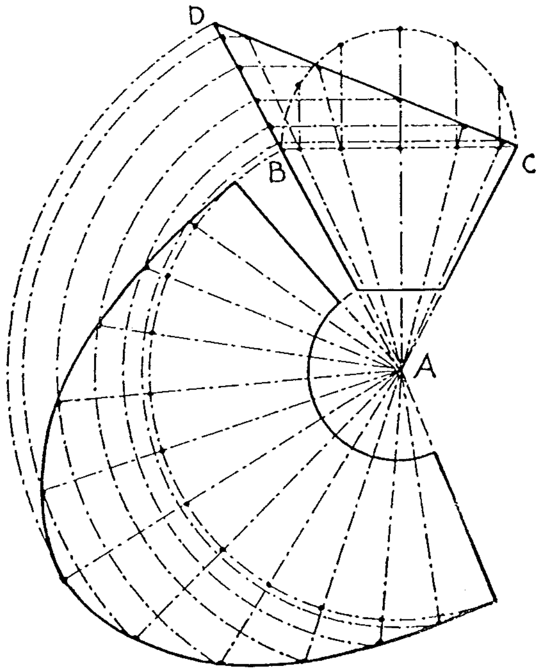
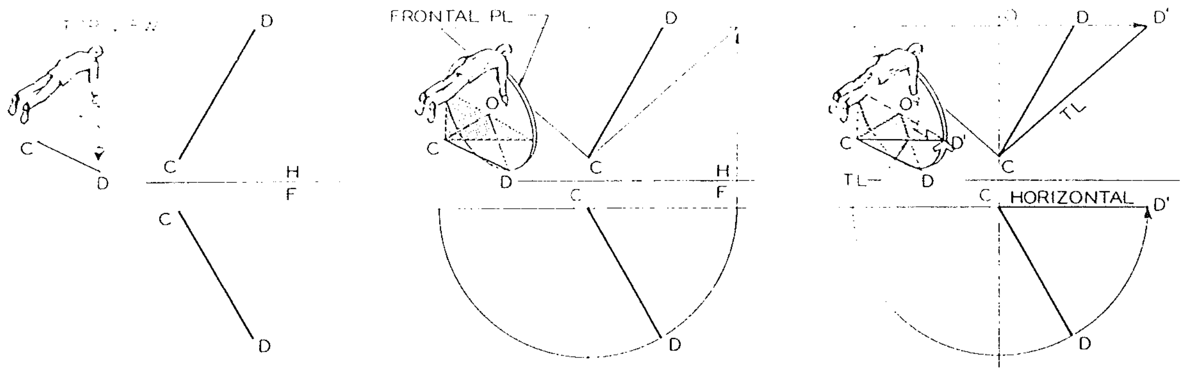


Fig. 10. Development of a watering can rose body in the shape of a frustrum of a right cone. This example shows how even a fairly simple component requires a lot of construction lines. DICKASON (1967, p. 38)

FIGURE 10–7. TRUE LENGTH OF A LINE IN THE TOP VIEW



Given: The top and front views of line *CD*.

Required: Find the true-length view of line *CD* in the front view by revolution.

Step 1: The front view of line *CD* is used as a radius to draw the base of a cone with point *C* as the apex. The top view of the cone is drawn with the base shown as a frontal plane. The axis, *CO*, is perpendicular to the frontal base.

Step 2: The front view of line *CD* is revolved into position *CD'* where it is horizontal. When projected to the top view, *CD'* is the outside element of the cone and is true length.

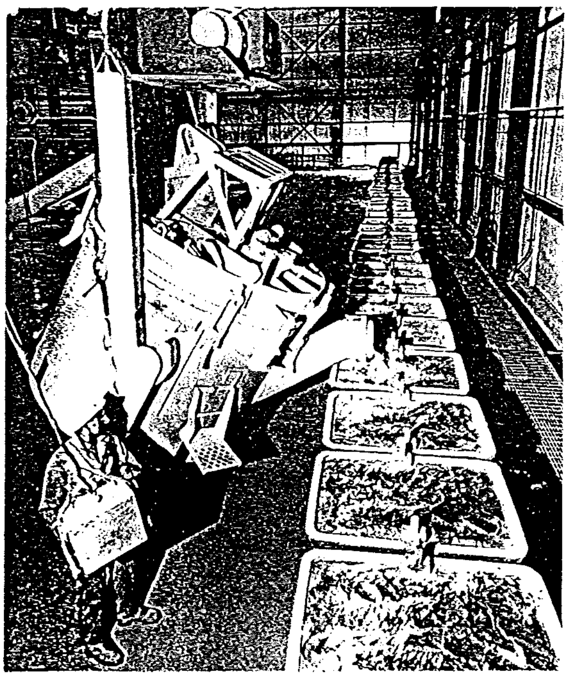
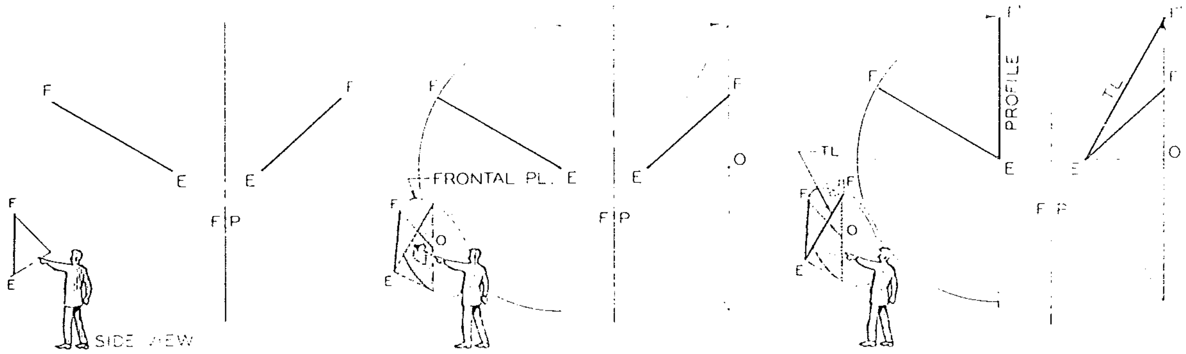


Fig. 10–8. The crucible used to pour 700-pound ingots of aluminum was designed to revolve about an axis to the position required for efficient flow of metal. (Courtesy of ALCOA.)

Fig. 11. The use of a man and a photograph of an impressive object in illustrating the concept of revolution. EARLE (1977, p.268)

FIGURE 10–9. TRUE LENGTH OF A LINE IN THE SIDE VIEW



Given: The front and side views of line *EF*.

Required: Find the true-length view of line *EF* in the profile view by revolution.

Step 1: The front view of line *EF* is used as a radius to draw the circular view of the base of a cone. The side view of the cone is drawn with a base through point *F* that is a frontal edge.

Step 2: Line *EF* in the front view is revolved to position *EF'* where it is a profile line. Line *EF'* in the profile view is true length, since it is a profile line and the outside element of the cone.

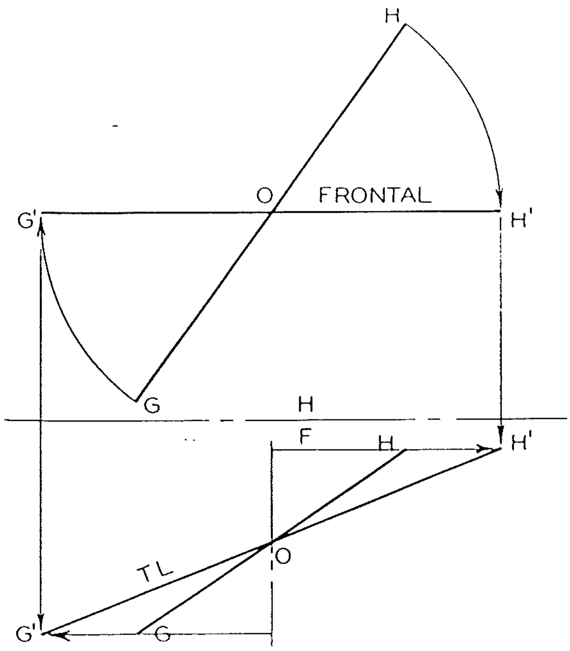


Fig. 10–10. The axis of revolution used to find the true-length view of a line can be placed anywhere on the line to be revolved. In this case a vertical axis was placed through point *O* of line *GH*.

The portable well work-over equipment and the pump shown in Fig. 10–11 illustrate revolutions about an axis. The design of each was analyzed by revolution principles to refine and develop operational functions.

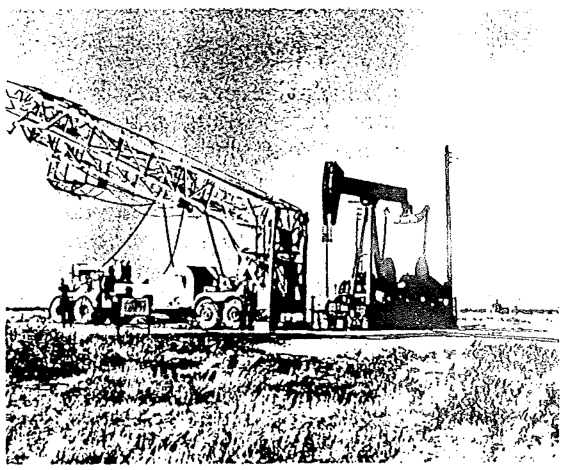
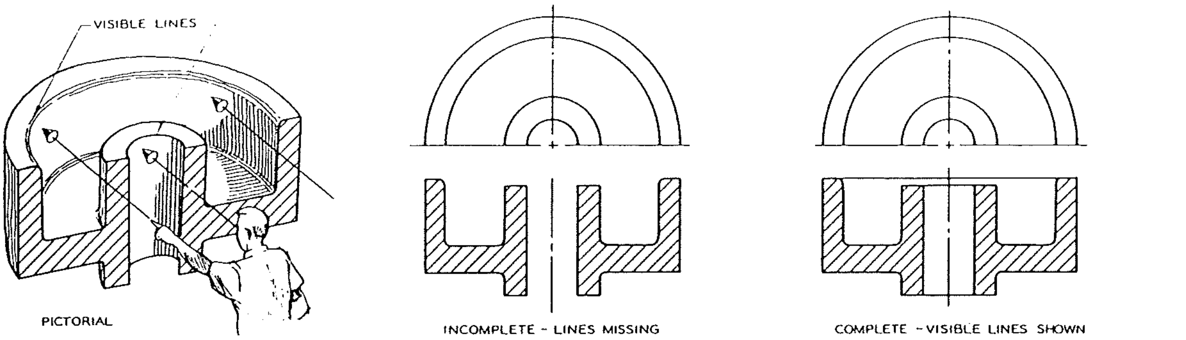


Fig. 10–11. The portable well work-over equipment and the pump are examples of mechanisms that were designed to revolve about an axis into a variety of positions. (Courtesy of Exxon Corporation.)

Fig. 12. Further use of a man and a photograph in illustrating the concept of revolution. EARLE (1977, p. 269)

FIGURE 5–95. FULL SECTION THROUGH A CYLINDRICAL PART



A. When a full section is taken through an object, you will see lines behind the sectioned area.

B. If only the sectioned area were shown, the view would be incomplete.

C. Visible lines behind the section must be shown also.

5–35 PARTS NOT SECTIONED

More clarity may be obtained in sections if some of the more standard parts are not section-lined even though the cutting plane passes through them. An example section is shown in Fig. 5–96A, where nuts, bolts, shafts, and keys are not section-lined. These parts have no internal features and the representation would not be improved if they were section-lined. Other parts not section-lined are ribs, spokes, webs, ball and roller bearings, rivets, pins, and similar standard parts. The section in Fig. 5–96B gives examples of shafts, bolts, washers, and roller bearings that are not section-lined even though the cutting plane passes through

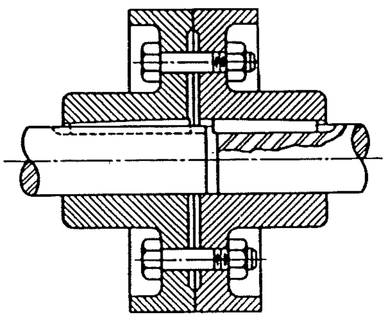


Fig. 5–96A. Parts not section-lined in an assembly—shafts, keys, bolts, and nuts. (Courtesy of ANSI; Y14.2–1957.)

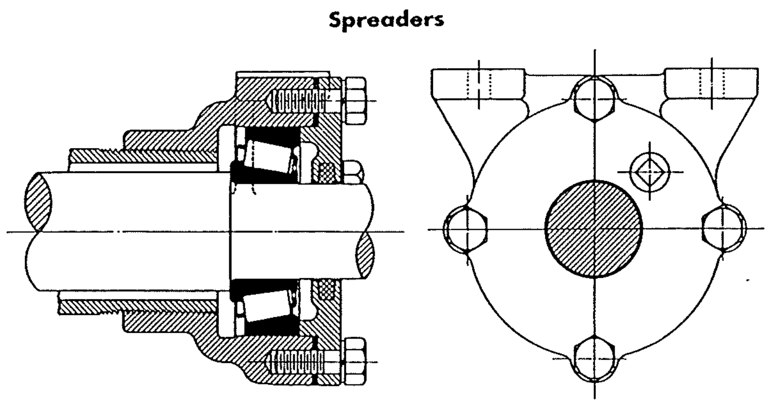


Fig. 5–96B. An example of parts not section-lined in an assembly—shafts, bolts, and roller bearings. (Courtesy of *Timken Engineering Journal.*)

Fig. 13. Explanatory illustrations to convey the concept of a sectional view. Note the use of the man in the pictorial view. Parts not sectioned, drawn to American standard ANSI which differs to BS 308. EARLE (1977, p. 127)

4.2 Types of line and their applications

4.2.1 Two thicknesses of lines are recommended; Table 2 shows their applications, thicknesses and proportions.

Table 2. Types of line

Example (letters refer to Fig. 6)	Type of line	Line width	Example of application
A	Continuous (thick)	mm 0.7	Visible outlines and edges
B	Continuous (thin)	0.3	Fictitious outlines and edges Dimension and leader lines Hatching Outlines of adjacent parts Outlines of revolved sections
C	Continuous irregular (thin)	0.3	Limits of partial views or sections when the line is not an axis
D	Short dashes (thin)	0.3	Hidden outlines and edges
E	Chain (thin)	0.3	Centre lines Extreme positions of moveable parts
F	Chain (thick at ends and at changes of direction, thin elsewhere)	0.7 0.3	Cutting planes
G	Chain (thick)	0.7	Indication of surfaces which have to meet special requirements

Fig. 14. Types of line commonly used in engineering drawing.
(BS 308: Part 1: 1972, p.9)

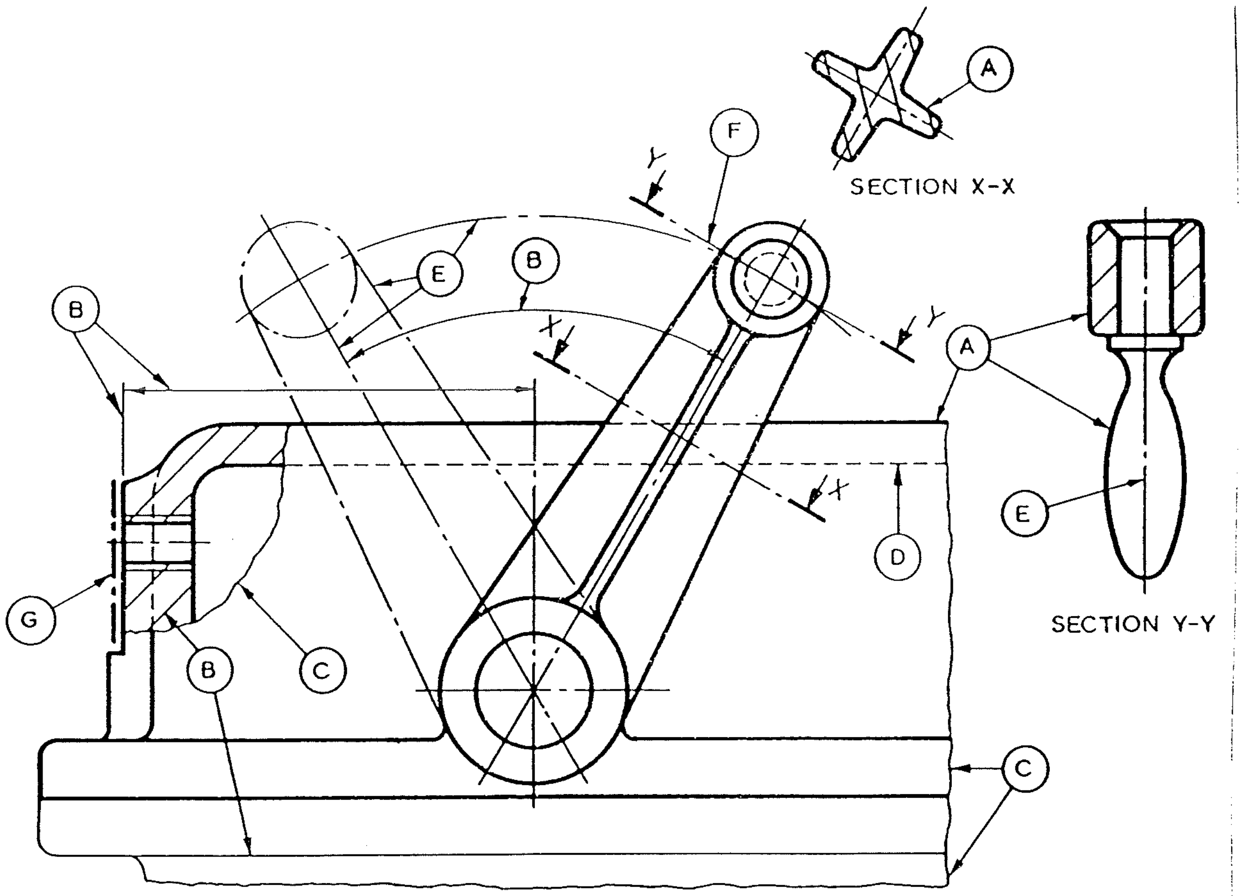


Fig. 15. Application of various types of line in engineering drawing. This illustration includes examples of partial sectional views. (BS 308: Part 1: 1972, p.10)

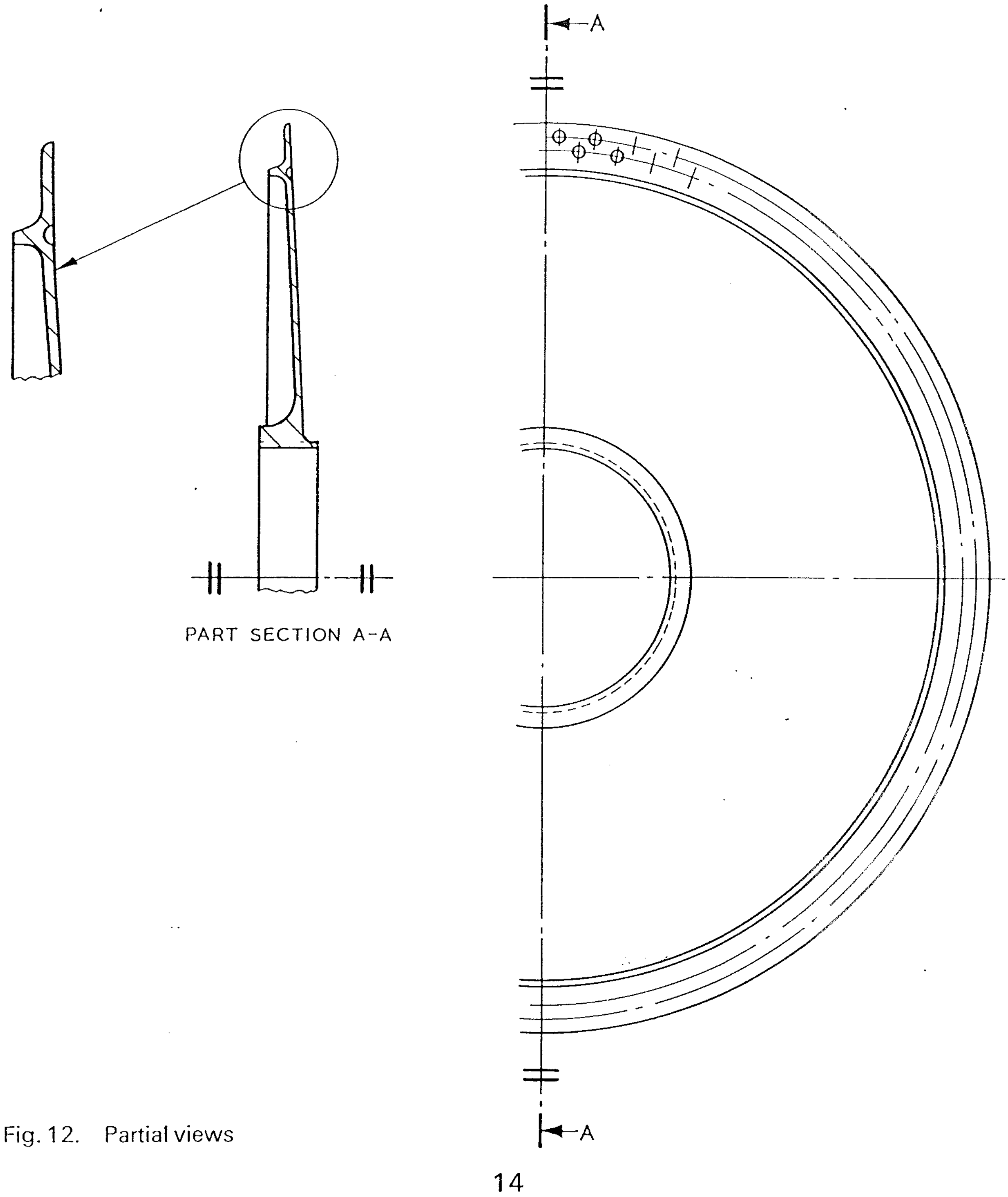


Fig. 16. Partial views including a removed partial sectional view.
(BS 308: Part 1: 1972, p.14)

Where sections of the same part in parallel planes are shown side by side, the hatching lines should be similarly spaced, but offset along the dividing line between the sections (see Fig. 26).

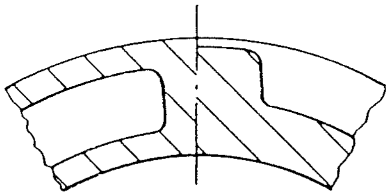


Fig. 26

8.3 Thin sections

Thin sections may be shown as single thick lines in preference to showing the material thickness out of scale. When adjacent parts are thus shown a space may be left between them for clarity (see Fig. 27).

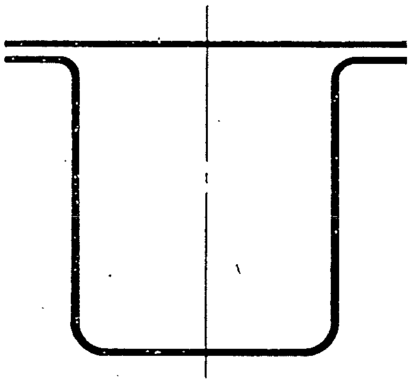


Fig. 27

8.4 Ribs, etc.

In principle, ribs, bolts, shafts, spokes of wheels, and the like should not be shown in longitudinal section (see Fig. 28).

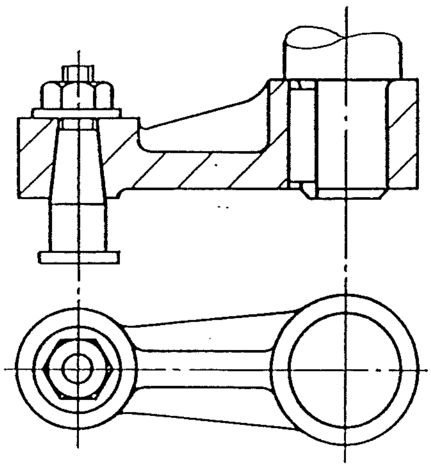


Fig. 28

8.5 Half sections

Symmetrical parts may be drawn half in outside view and half in section (see Fig. 29).

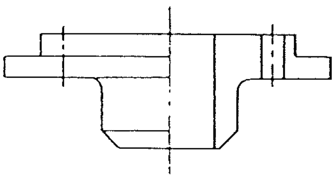


Fig. 29. Detail in half section

Fig. 17. A selection of sectional views for different applications.
(BS 308: Part 1: 1972, p.19)

Appendix C. A typical drawing and layout of drawing sheet

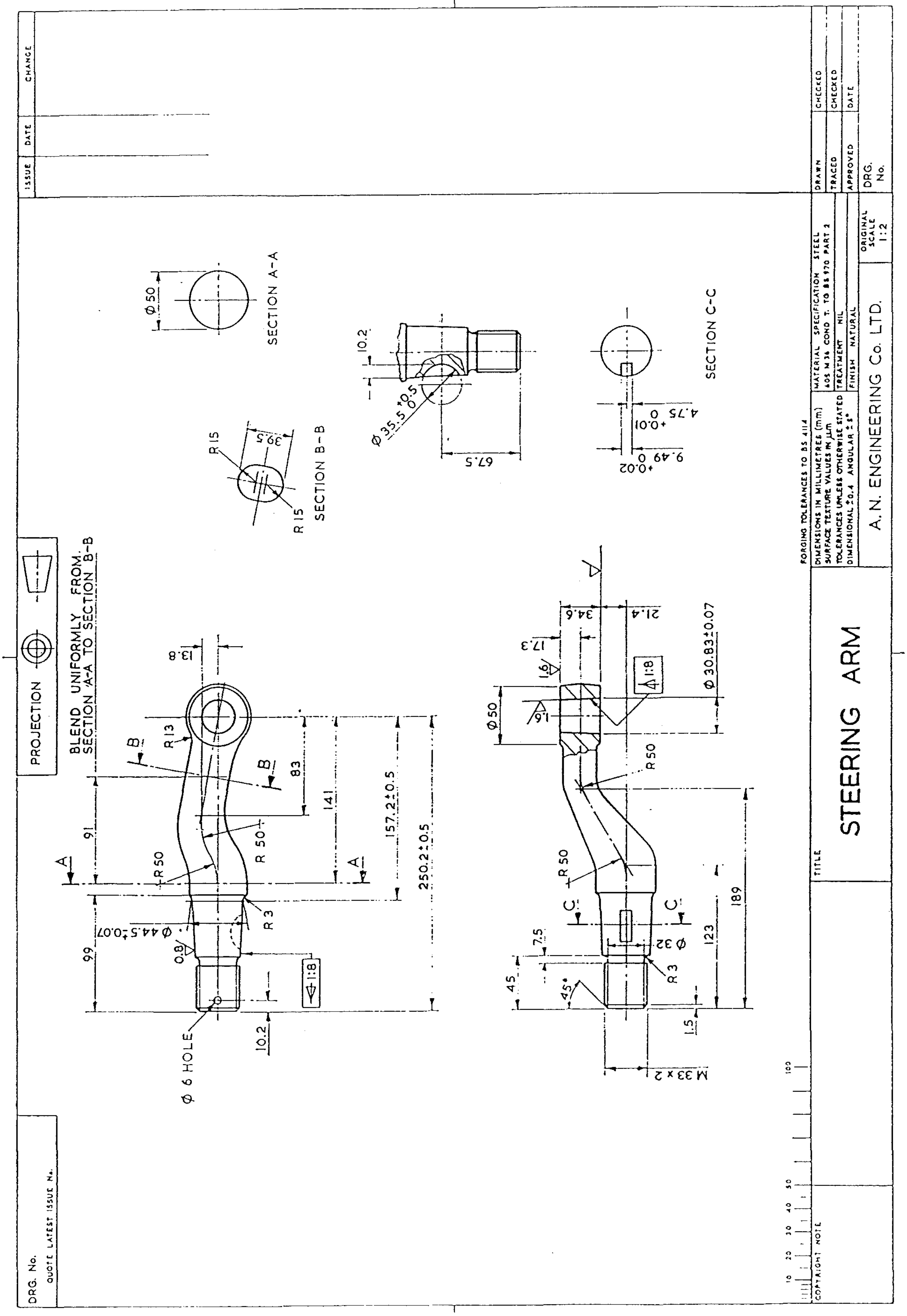
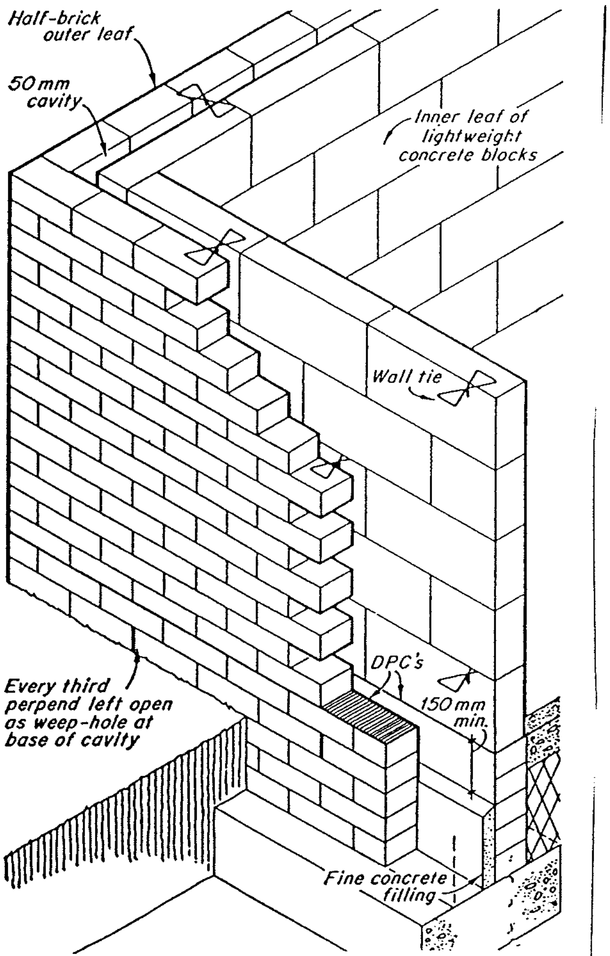
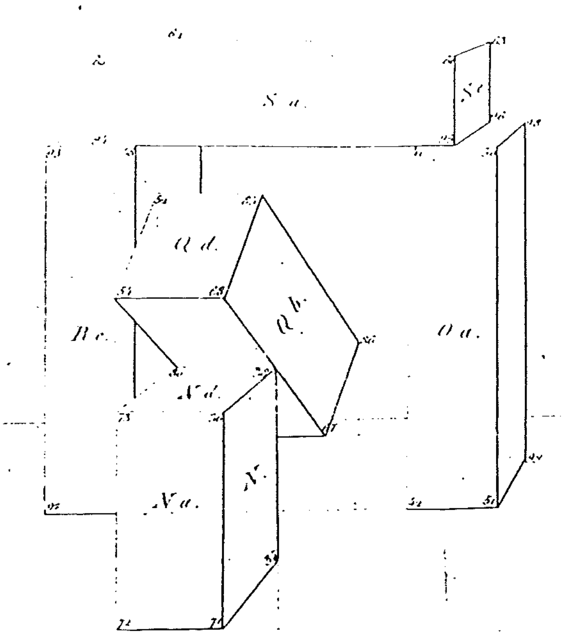


Fig. 18. A typical engineering drawing. (BS 308: Part 2: 1972, p39)



68 Cavity wall construction

Fig. 19. A typical isometric illustration from a building construction science texbook.(FOSTER, 1983, Structure & Fabric Part 1, Mitchell's Building Series, Batsford, London)



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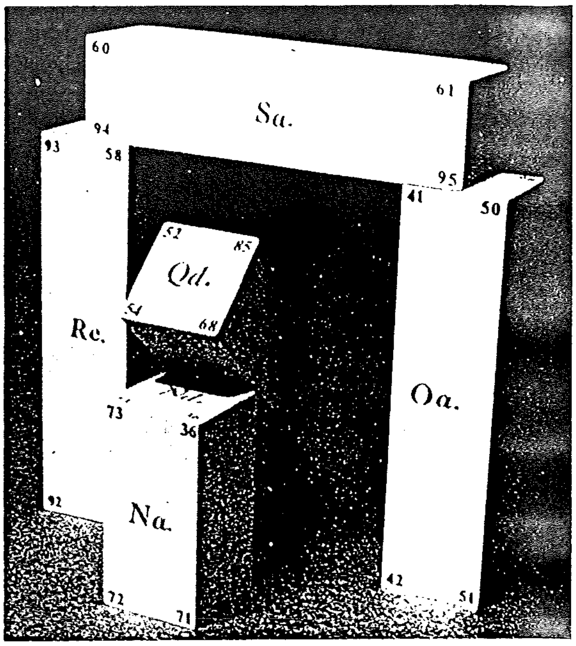
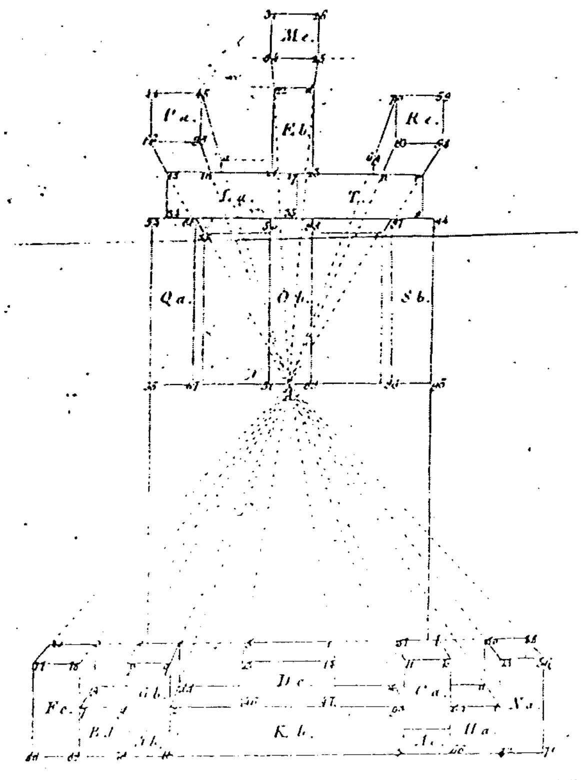


31

30. Peter Schmid *Das Naturzeichnen*, Part I (1828), Plate XIII. 175 X 205 mm.
31. Scale reconstruction of *Das Naturzeichnen*, Part I, Plate XIII

32. Peter Schmid *Das Naturzeichnen*, Part I (1828), Plate XXIV. 210 X 175 mm.
33. Scale reconstruction of *Das Naturzeichnen*, Part I, Plate XXIV

32



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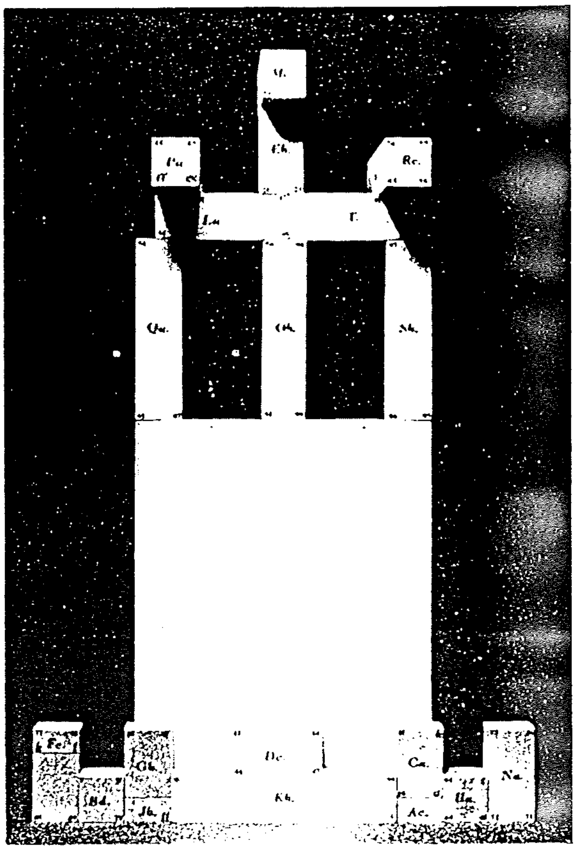


Fig. 20. Drawings and photographs of wooden blocks arranged in a similar way. Note the use of labelling and an error block Q, corner 67 is drawn off the ground plane. ASHWIN (1982)

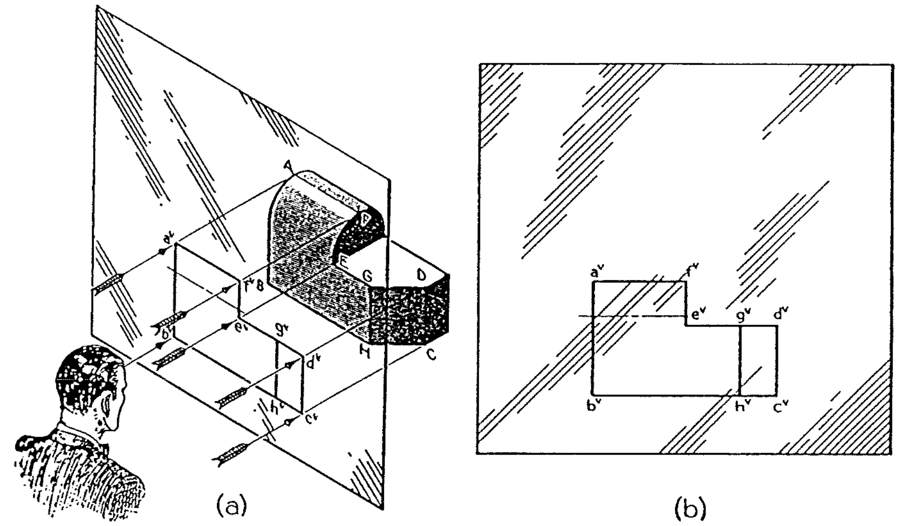


FIG. 248 Projection of an Object.

Fig. 21. Pictorial illustration and orthographic view the notion of projection. GIESECKE et al (1949, p. 157)

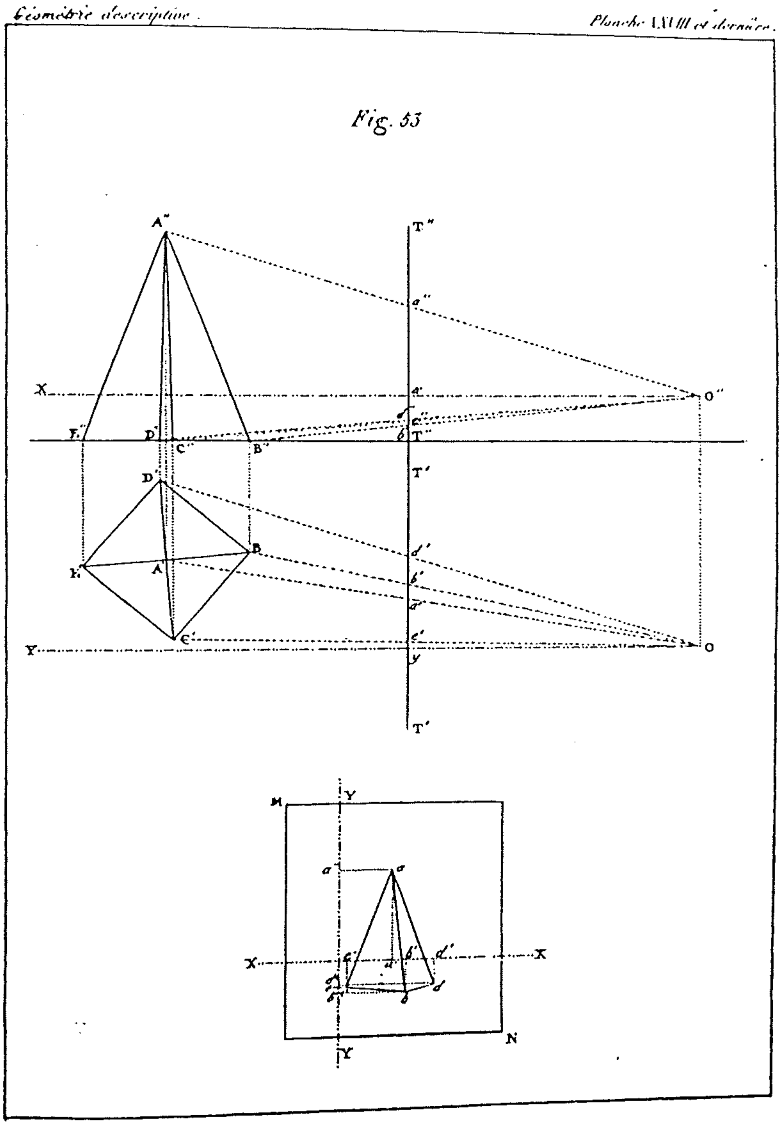


Fig. 45. Monge's application of descriptive geometry axioms to perspective projection, added to a late edition of *Géométrie descriptive* after his death. Compare with Fig. 18.

Fig. 22. The use of X and Y axes but not the Z axis. MONGE (1847) reproduced in BOOKER (1979, p. 105)

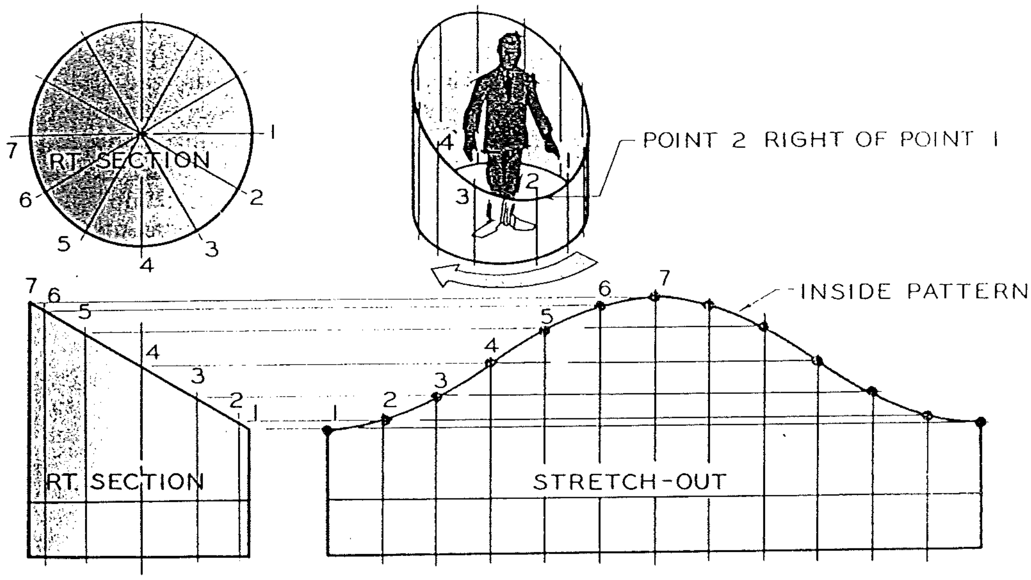


Fig. 12–10. Development of a cylinder.

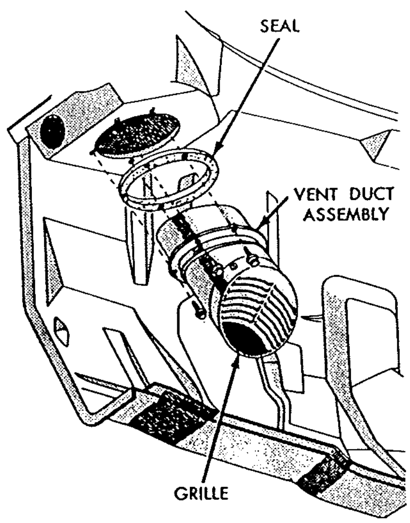


Fig. 12–11. This ventilator air duct was designed through the use of development principles. (Courtesy of Ford Motor Company.)

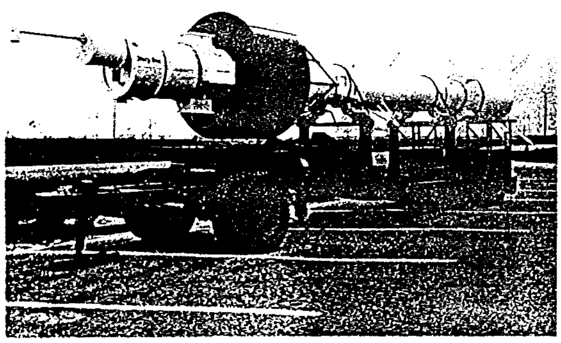


Fig. 12–12. Cylindrical developments were necessary in the design of the Hydra 5 launch vehicle. (Courtesy of the U.S. Navy.)

Fig. 23. Use of a man to help convey the relationship between the object and the method used to determine its development. Note the use of photographs to impress the learner with the relevance of the topic. EARLE (1977, P. 319)

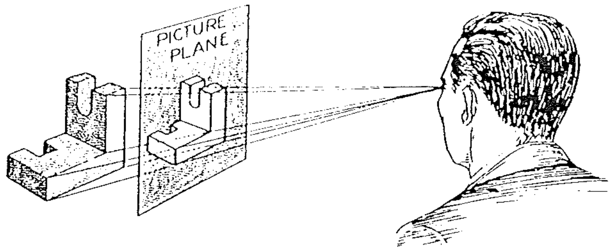


Fig. 5.1 Perspective projection.

5.3. Orthographic Projection (Parallel Projection). If the observer in Fig. 5.1 moves straight back from the picture plane until he is an infinite distance from it, the projecting lines (projectors) from the eye to the object become parallel to each other and perpendicular to the picture plane. The resulting projection (Fig. 5.2) will then be the same shape and size as the front surface of the object. From a practical viewpoint, the projection may be thought of as being formed by perpendicular projectors extended from the object to the plane. The view is called an *orthographic projection.*

Since the view shown in Fig. 5.2 does not reveal the thickness of the object, one or more additional projections (Fig. 5.3) are necessary to complete the description. Two projections are usually sufficient to describe simple objects, but three or more are necessary for complicated ones.

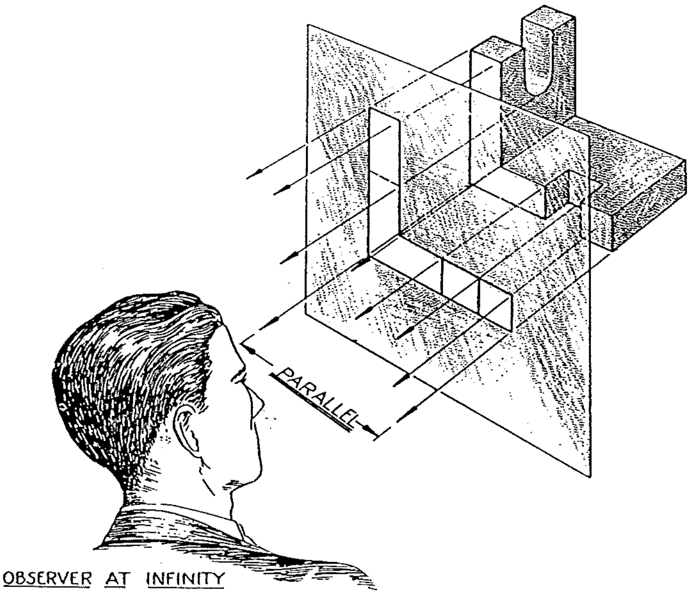


Fig. 5.2. Orthographic projection.

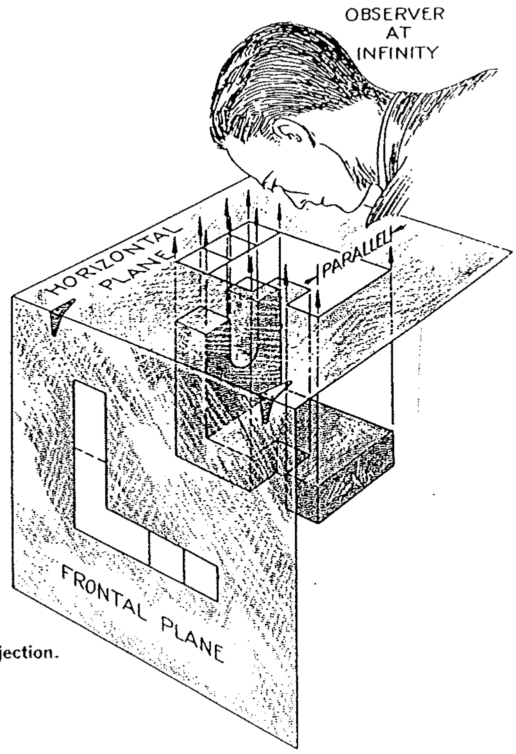


Fig. 5.3. Planes of projection.

Fig. 24. Use of a man to help communicate the idea of orthographic projection. LUZADDER (1968, p. 82)

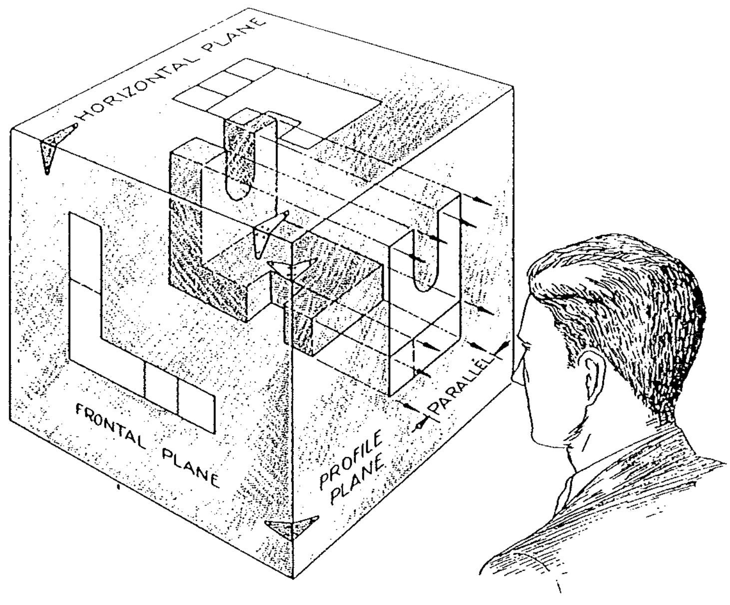


Fig. 5.4. Planes of projection.

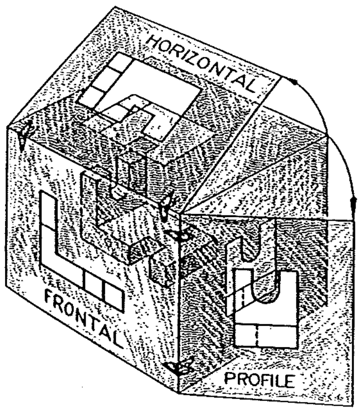


Fig. 5.5. The revolution of the planes of projection.

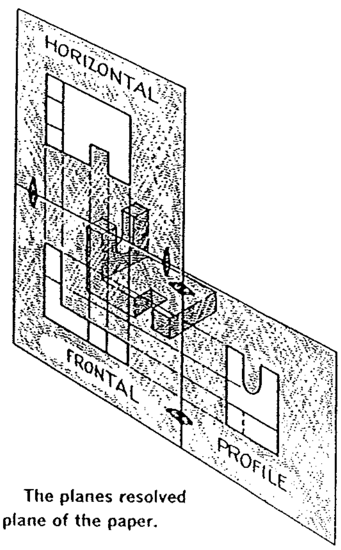


Fig. 5.6. The planes resolved into the plane of the paper.

Fig. 25. Planes of projection shaded pictorial views. Note the use of a man to help orient the learner. LUZADDER (1968, p. 83)

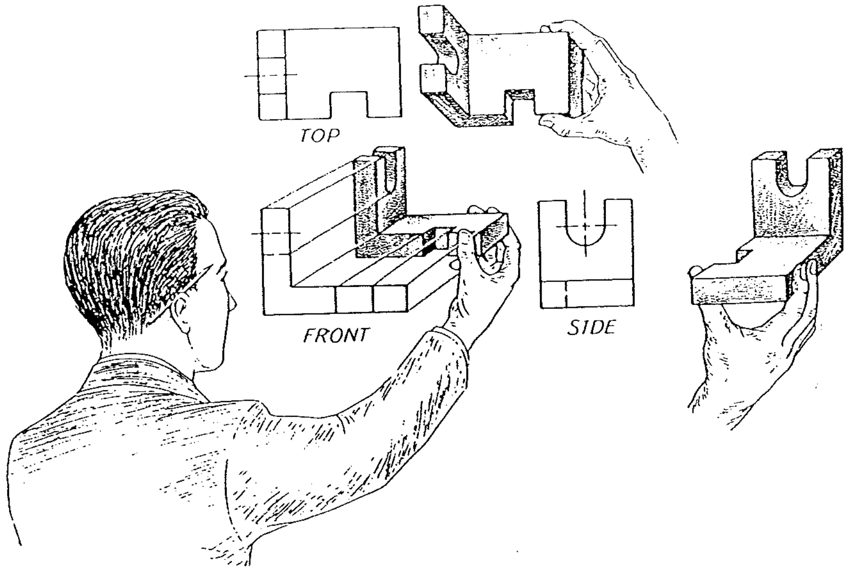


Fig. 6.2. Obtaining three views of an object.

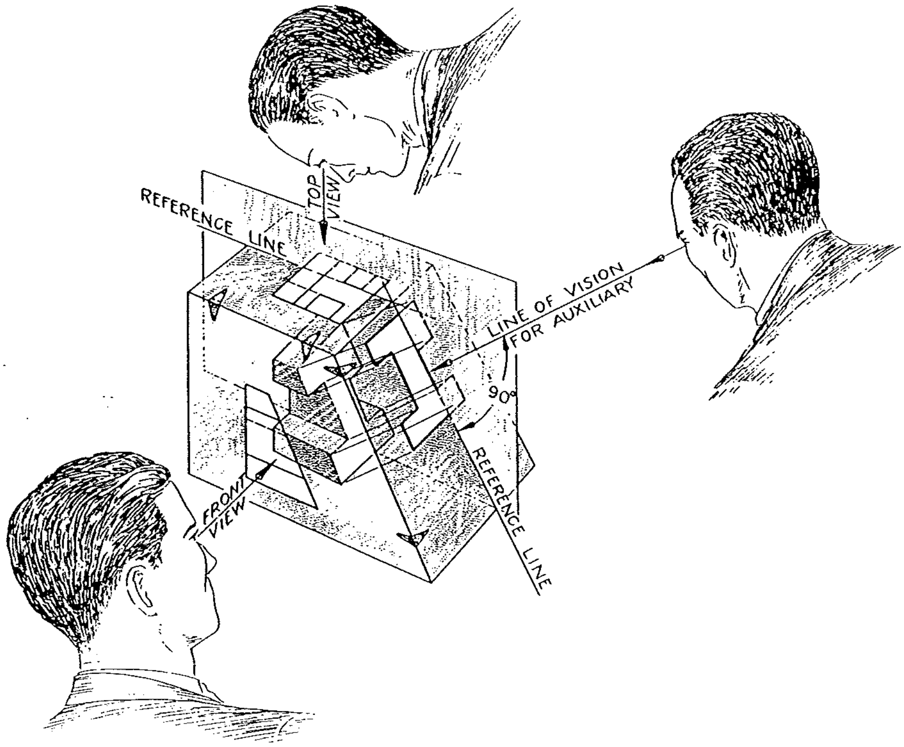


Fig. 8.1. Theory of projecting an auxiliary view.

Fig. 26. The use of a man in two illustrations to help the learner understand the relationship between projections and the object.
LUZADDER (1968, p.88, 142)

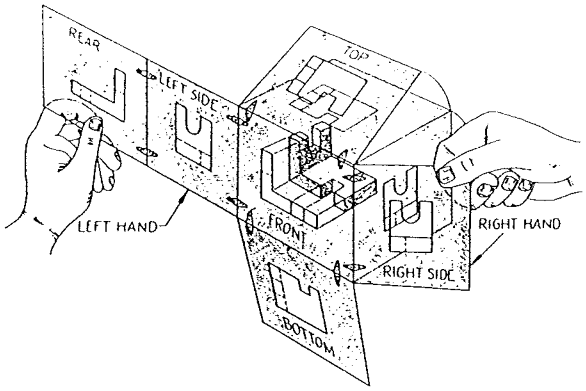


Fig. 6.5. Opening the glass box.

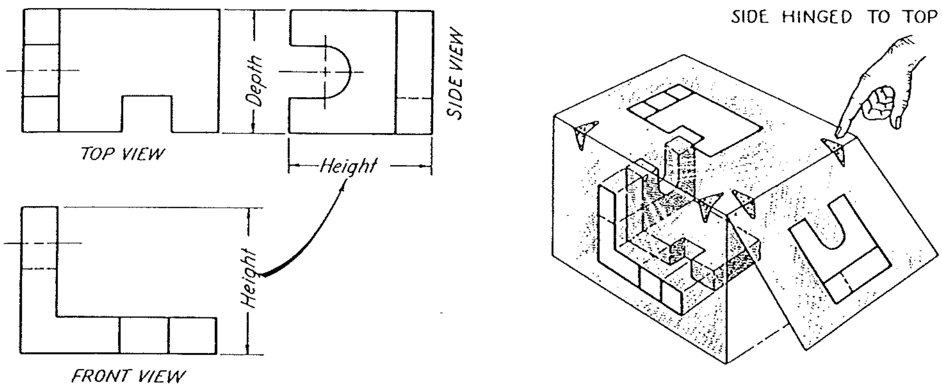


Fig. 6.7. The "second position" for the side view.

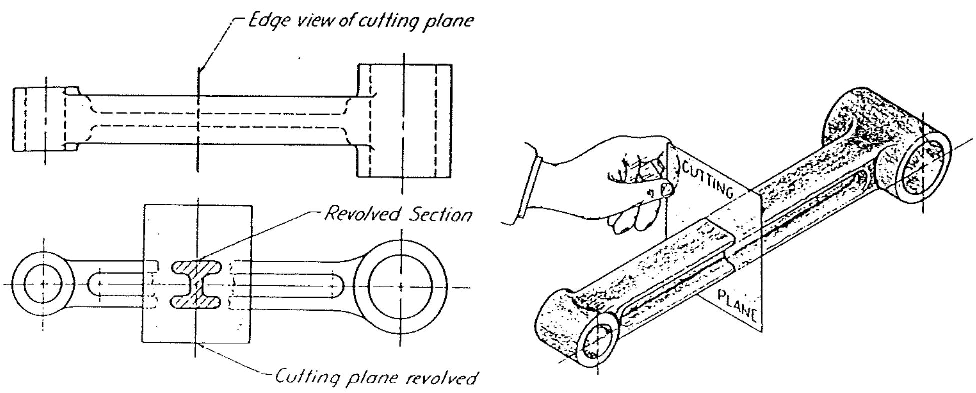


Fig. 9.9. A revolved section and cutting plane.

Fig. 27. Three pictorial illustrations using hands to help the learner understand the relationship between orthographic views and the object. LUZADDER (1968, p.90-91, 165)

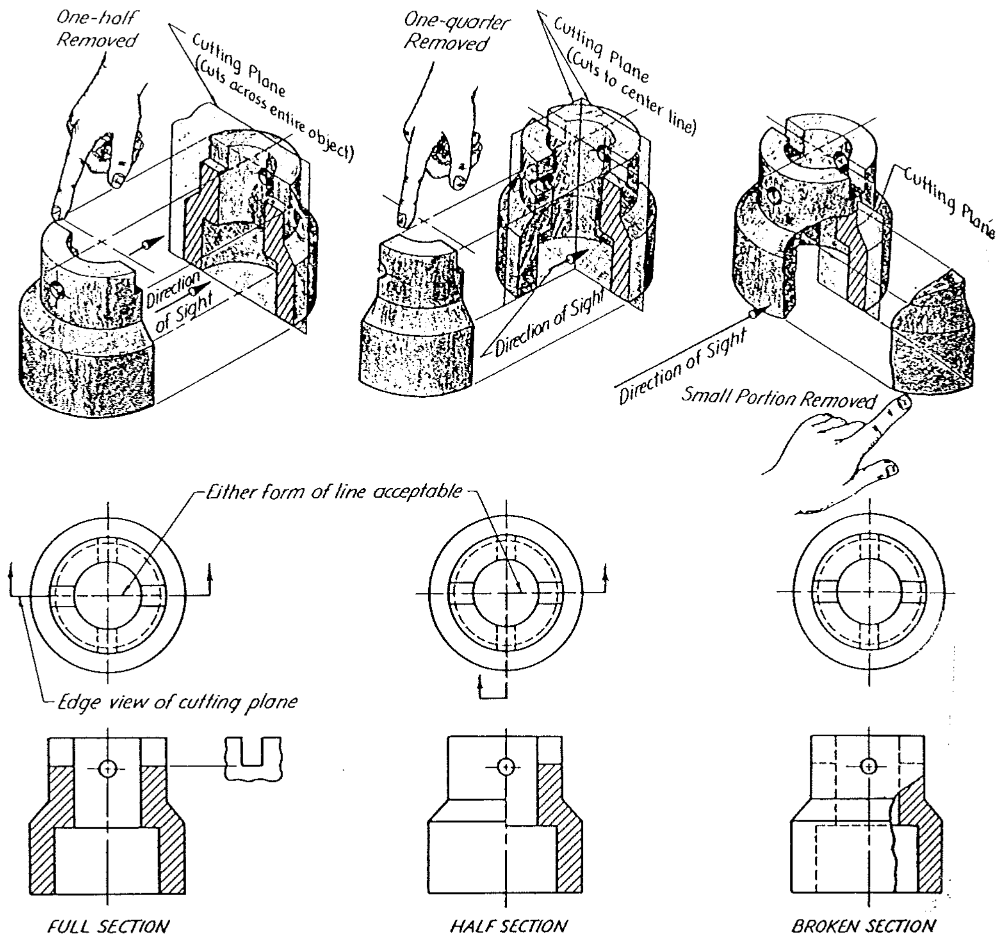


Fig. 9.5. Types of sectional views.

Fig. 28. Types of sectional view. Note the illustrator's use of the hand to emphasise the removal of part of the object. LUZADDER (1968, p. 164)

Differentiation

The examination is based on common papers for all candidates. Differentiation is achieved in the following ways :

(a) Paper 1: through structured questions which allow candidates to demonstrate their ability in full without penalising the less able candidate.

(b) Paper 2: through a design assignment which is capable of solution at a variety of levels.

(c) Through structured course work where centres present tasks appropriate to individual levels of ability.

LONDON & EAST-ANGLIAN EXAMINATION GROUP

CDT: DESIGN AND COMMUNICATION SYLLABUS 1150

SYLLABUS

The syllabus is written in two parts:

Part 1 is the common core syllabus which will form the basis of work for all candidates.

Part 2 consists of four areas of study. The areas of study are :

(i) Mechanical Systems

(ii) The Built Environment

(iii) Product Graphics

(iv) Computer Graphics

NOTE: *Candidates should follow the core syllabus (Part 1) and* two *areas of study (Part 2).*

The areas of study are intended to help teachers and pupils focus on specific aspects of Design and Communication and promote opportunities for study in depth.

The intention is that the areas of study should flavour the whole Design and Communication Course and that they should be strongly represented in the course work presented at assessment time. It is not expected that the common core syllabus or the areas of study will be taught as separate entities.

It is expected that centres will use Part 1 and Part 2 of the syllabus in ways which support their teaching and which capitalise on the facilities available. For example, a complete teaching group may follow themes chosen by the teacher or, alternatively, individual pupils within a group or groups may follow separate themes guided by the teacher. This flexibility should allow candidates who have access to computer facilities to apply their knowledge in a designing and making form within any of the areas of study.

SYLLABUS CONTENT

Part 1 — COMMON CORE

	Topic	Objective	Notes
A	DESIGN SKILLS	*Candidates should be able to*	
1.	Identification and analysis of problems	respond appropriately to a problem either given to, or generated by them, and record its important factors.	Emphasis should be given to the efficient use of clearly-presented notes and annotated sketches.
2.	Specification and consideration of constraints	collect together the key factors which affect the development of the solution ;	this should take into account considerations of aesthetic, technical, economic and moral factors where appropriate.
3.	Searching and ordering data and information	select and communicate relevant data from available resources and systems;	
4.	Synthesis	combine the results of analysis and specification to generate a range of initial ideas and possible solutions;	
5.	Solution	develop a chosen solution into a finished drawing, model or prototype;	
6.	Evaluation	assess the suitability of the solution and show evidence of modification where necessary;	
B	MAKING SKILLS		
1.	Mock-up and kits	use mock-up and kits to simulate principles and the function of ideas;	
2.	Models	make and use models to prove and communicate a final solution;	Photographs may be used to record the resolution of solutions by such models.
3.	Application of mock-up, kits and models	recognise and test the geometric principles of true shapes and solids; demonstrate and test structural principles; test visual aspects of an idea; test the effect of form, colour and texture;	Candidates should be encouraged to recognise the value of modelling in appreciating the aesthetic qualities of ideas and proposed solutions to problems.
C	COMMUNICATION SKILLS		
1.	Freehand sketching and drawing	show the important of producing drawings simply and quickly for the purpose of *(a)* recording thoughts, *(b)* communication and explanation of ideas and systems; sketch orthographic views from pictorial sketches (and vice versa) use short and concise forms of annotation to aid the presentation of ideas; indicate the overall size and proportion using dimensions when necessary; produce simple exploded drawings to indicate assembly, movement and location;	

	Topic	Objective	Notes
1.	Freehand sketching and drawing *(cont.)*	*Candidates should be able to*	
		select appropriate methods of presentation;	
		use shading, colouring, and other techniques for emphasis;	
2.	**Formal instrument drawing**	use instruments to achieve good standards of graphic presentation;	In the examination, candidates must have good quality drawing equipment such as : A2/A3 drawing board with either Tee square, parallel action or draughting machine, 30 °/60 ° set squares, protractor, compasses, dividers, pencils, erasers.
		select suitable layout of drawings to achieve visual impact and clarity;	
		demonstrate a good standard of drafting ability for effective communication;	
		select and use the most appropriate scale when drawing;	Conventional scale notation should be used (e.g. 5 : 1)
	2.1 Types of formal drawing		
	(i) Orthographic	read and understand orthographic drawings	Drawings to conform to PD 7308
		select the most suitable views and angles of projection;	
		read and draw in both first and third angle projection and use associated symbols;	
		make appropriate orthographic drawings with dimensions when required;	To conform to PD 7308
	(ii) Pictorial	read and understand selected forms of pictorial representation;	These should include isometric and perspective views. Candidates should be aware of other pictorial forms, such as oblique and planometric, but they will not be examined in the drawing of these views. The use of perspective or isometric scales will not be required.
		make drawings in isometric;	To include the construction, by co-ordinates, of circles and curves in isometric.
		make drawings in two-point perspective;	Measured perspective will not be required but an understanding of the effect of differing vanishing points will be expected.
		use where necessary, shading, colouring, and other techniques for emphasis;	To include use of various pencil grades of coloured crayons and colour media. To include techniques for emphasising object shape and surface texture.
	(iii) Assembly and component drawing	recognise the need for assembly and component drawing;	
		produce drawings which show the relative location and positioning of components;	Drawings may be in orthographic or pictorial form. Use should be made of sectional and exploded views both projected and removed.
		indicate on drawings the movement of parts relative to each other;	

	Topic	Objective	Notes
		Candidates should be able to:	
3.	Drafting aids	use aids to develop good drafting techniques;	Such aids are likely to include: templates, French curves and flexi-curves, lettering, stencils and dry transfer lettering. *Where computer facilities are available it is expected that candidates will make full use of these resources.*
4.	Lettering	use freehand pencil-lettering techniques which emphasise clarity, proportion and uniformity of presentation;	Note PD 7308
5.	Symbols	recognise the principles behind the use of symbols;	Reference to PD 7307 may be helpful.
		identify and draw common symbols;	Symbols may be grouped in terms of — informative, directional, mandatory, warning, hazard/safety, representative or instructional.
6.	Charts and diagrams	read charts and diagrams which illustrate a sequence of procedures or operations;	Examples would include workshop manuals, instructional diagrams and flow charts.
		transfer information and data into chart and diagrammatic forms;	Examples would be : line, bar, block and pie charts and picto- and histograms.
D	KNOWLEDGE		
1.	Control	recognise that different forms of control system exist;	Examples can be drawn from human, mechanical electrical/electronic etc.
		understand the need for a control system as a regulator between a desired output and possible inputs;	Candidates would need to know a desired output
		Show evidence that one form of control system and its application has been studied;	Detailed knowledge of such a system is not required but there should be appreciation of (i) general principles of operation, (ii) relative power required, (iii) general efficiency.
2.	Energy	recognise that different forms of energy sources exist;	Candidate should realise that common domestic and industrial energy supplies have derived by conversion from fossil fuels.
		show evidence that one form of energy source and its applications have been studied;	Study should be restricted to sources commonly available in a school, college or domestic environment e.g. batteries, power packs, butane gas, mains water pressure, bicycle or car air-pumps.
3.	Materials and components	differentiate between wood, metal and plastics by reference to their inherent qualities and working characteristics;	No calculations are required but pupils should be able to select materials for their qualities in terms of (i) mechanical thermal or electrical properties; (ii) structural properties in either basic form (e.g. plank, bar sheet) or constructed form (e.g. triangulation, honeycomb, corrugation); (iii) ease of manipulation to desired shape or structure.
		understand simple methods of forming, shaping and joining materials, principally wood, metal and plastics;	Pupils are expected to build upon knowledge gained in the foundation courses.

	Topic	Objective	Notes
		Candidates should be able to:	
3.	Materials and components *(cont.)*	demonstrate knowledge of common components associated with the use of metal, wood and plastics;	
		demonstrate knowledge of material and components used in mock-ups and model-making;	For example : polystyrene, foam, plasticine, cardboard; thin off-cuts of sheet material such as ply, acrylic, aluminium; various adhesives, tapes, staples and clips: a variety of 'scrap' items such as tins, tubes, cartons, boxes, rods, bars etc., construction kits containing gears, wheels and pulleys, sectional metal and plastic strips.
4.	Geometric principles		
	Solids	recognise and name the following regular solids: square, hexagonal and triangular prism, pyramid, cylinders and cones;	
		identify the component shapes of these regular solids;	i.e. circles or parts of circles, triangles and rectangles.
	Constructions	draw and construct	
		a perpendicular, common angles (30 °, 45 °, 60 °), sub-divisions of length, hexagon, octagon, pentagon, isosceles and equilaterial triangles, ellipses, plotting of loci;	
		understand that flat shapes (i.e. surfaces) may be developed into and from solid forms	
		produce developments for and from solids to meet design problem requirements;	This will include the techniques of developing true surface shapes or holes of inter-penetrating parts.
5.	**Interpretation and use of drawings**	understand that all drawings are needed for a specific readership and purpose;	Wherever possible candidates should be encouraged to identify the purpose for which a drawing is made, i.e. what needs to be communicated and to whom.
		choose appropriate drawing techniques for specific purposes;	
6.	Graphic Design and Society	use the design, make and test process to understand and illustrate the inter-relationship between design, technology and the needs of society;	It is expected that both in the work undertaken in the classroom and within the framework of project, candidates will be encouraged to consider design, both graphic and structural as it will affect the society in which they live. In the examination questions will be set which will foster a social awareness of design in its broadest sense.
7.	Ergonomics and anthropometrics	understand the basic principles of anthropometrics;	The collection and study of human body measurement. Calculations are not required nor is comparison of dynamic and static systems. Reference should be made to PD 7302.
		understand the basic principles of ergonomics	Making the task fit the operator.
		apply the principles of ergonomics and anthropometrics to a simple design problem;	It is expected that this would include making or using a simple ergonome to aid a solution.

Part 2 – AREAS OF STUDY

Candidates should select TWO areas of study to follow.

(i) Mechanical Systems

This area of study is intended to encourage the investigation, study and analysis of various mechanical systems which form integral parts of the home, the school and the working environment. It is expected that candidates will be given opportunities to appreciate the nature of mechanical forces through the study of mechanisms used in real situations and encouraged to recognise the possibilities for modification and adaptation to such systems.

Possible studies might be drawn from the list below:

garden equipment including mowers, trimmers, barrows, collapsible furniture, washing-line systems;

kitchen and bathroom equipment including taps, valves, washing machines, driers, food processors, floor cleaning devices;

DIY type of equipment including electric drills and attachments, workbenches, jigs and tools associated with light building and decorating;

transportation – bicycle, motorbike, automobile, caravan, prams, trolleys and trailers;

building fixtures and fittings such as locks, catches, window mechanisms, furniture hinges, stays and supports, mechanical blinds and vents;

mini-mechanics associated with audio equipment, record and tape players, sewing machines, typewriters, computer disc drives and printers;

school equipment including machinery and facilities in departments such as CDT, sports and recreation, science, technology and audio-visual.

Note – *In this area of study formulae and their application will* not *be required at examination.*

	Topic	Objective	Notes
		Candidates should be able to	
1.	Design	select and name a mechanism to achieve a required change of movement from one prescribed form to another;	A train of mechanisms would not be required although a combination within one device may be required, e.g. screw jack including a ratchet.
		design a simple modification to a given mechanism in order to achieve a specified requirement;	Candidates would not be expected in the examination to draw the mechanism which is to be modified.
		design a simple device to satisfy a given function. This may utilise aspects of or parts of known mechanisms;	In the examination candidates would not be expected to design their own brief nor make a formal analysis.
2.	Communication	recognise, name and explain the function of a mechanism or device from a variety of illustrative material;	Sources may be: an actual mechanism or model, photographs, sketches, working drawings, assembly drawings, pictorial forms. Explanations may be in any form including annotated freehand sketches.
		use a variety of graphic techniques to record and illustrate the mechanisms studied.	Reference to PD 7302 may be helpful.

(ii) The Built Environment

This area of study is intended to encourage candidates to investigate aspects of the built environment, to analyse existing solutions to environmental problems and to offer alternative or modified ideas. It is recognised that centres may wish to widen their studies into other environmental issues and such investigative work can be recognised in the course work assessment. For the purposes of Paper 1, Section B, a broad understanding of the syllabus items listed below is expected.

Topic	Objective	Notes
	Candidates should be able to	
1. Design	recognise the main characteristics of common building materials and suggest applications;	This will be limited to sand, aggregate, cement, bricks, timber, roofing materials and finishing materials.
	understand building regulations relating to single storey houses;	IN PRINCIPLE ONLY relating to: foundations, damp proofing, drainage, insulation and roofing, heating and lighting.
	understand some of the key factors dictating types of shelter or accommodation;	The purpose or uses for a building e.g., business, commercial, communal, private dwelling.
	develop ideas for specific types of shelter or accommodation;	To meet specified purposes such as temporary shelter for refugee camps, or for expenditions. Solutions are likely to be most effectively expressed in the form of three dimensional models.
	make reasoned comparisons between different transport and communication systems;	For example, a comparison could be made between data transference by road, rail, air or by electronic systems.
	develop ideas for specific forms of transport and communication system which meet particular needs;	Examples might include the special needs of the handicapped or of mail order companies; ideas could be represented through three dimensional models or computer simulations.
2. Communication	understand key drawing conventions	Conventions and symbols restricted to those found in PD 7301
	use symbols to display main services	
	understand and use simplified maps of roads, rail links and flightpaths;	Examples could include London tube maps or motorway route maps.
	use graphic methods for showing traffic flow and preferred routes;	

(iii) Product Graphics

This area of study seeks to support the work of candidates who have developed expertise in the application of design skills to the communication of product design and product packaging. It is anticipated that three-dimensional modelling will form a significant part of this area of study.

Users of this area of study may find British Standards Leaflet SL45 helpful in indicating areas of consumer education which may be supportive to the syllabus items listed.

Topic	Objective	Notes
	Candidates should be able to	
1. Design	understand and apply the principles behind the functional aspects of packaging in its broadest sense, including the suitability of materials;	These principles are likely to include containing, sorting, the handling, protection in relation to cost, durability, disposability, safety.
	understand and evaluate the relationship between effective packaging and the information on it, if applicable;	Both verbal and graphic forms should be studied.

	Topic	Objective	Notes
1.	Design *(continued)*	*Candidates should be able*	
		understand and evaluate the effect of colour, shape and texture on the effectiveness of packaging;	These elements should not be regarded as later additions to such forms but as integral parts of the overall solution to a problem.
		develop simple forms of packaging and/or its display to meet specified requirements;	This could form part of a mini project.
2.	Communication	appreciate the principles of advertising for the promotion of sales;	Consideration should be given to social and economic factors.
		use appropriate methods of representing information;	Forms of chart, graph and diagram as well written information will be expected; the significance of logos, trade marks and house style should be included.
		produce charts and data sheets from given information.	This could include manufacturing, sales and promotion sources.

(iv) Computer Graphics

This area of study has been written to support centres which are developing the use of the computer as an aid to produce design and analysis. It is recognised that the numbers and level of sophistication of computer equipment available to centres will vary. The following list indicates the minimum equipment thought necessary to effectively cover computer graphics.

Candidates should have access to

(a) computer with VDU and data storage device,

(b) means of producing hard copy,

(c) Computer software of FOUR types, i.e.

(i) a form of LOGO

(ii) a paint-on-screen package,

(iii) a 2D package in which co-ordinate data can be stored,

(iv) a 3D package which allows simple manipulation of an image.

It is important that computer work should be taught in the context of its application to other parts of the syllabus.

	Topic	Objective	Notes
		Candidates should be able to	
1.	Design		
	Graphic system	show evidence of using one or more graphic systems to resolve an individual or group design problem/assignment;	Evidence most likely to be found in course work.
	Applications	show evidence of studying one example of the application of computer graphics in manufacturing industry;	The computer modelling of cars, footwear or engine parts might be used as examples.
		show evidence of the creative use of computer graphics, including simple animation;	Examples may be drawn from advertising film and TV

Topic	Objective	Notes
	Candidates should be able to	
2. Communication		
Operating a basic computer system	set up a computer and its peripherals to a working situation	
	input data from a keyboard and from a digitiser and/or alternative device;	
	derive output data to a screen and/or printer or plotter;	
	use computer storage and retrieval systems;	
Graphics programming and operating	write programs to produce lines and shapes using move and draw commands;	*In BASIC and LOGO only.*
	operate commercial programs using shapes, colour and movement;	
	show understanding of the use of X, Y and Z axes;	
	understand and apply commonly used functions and terms;	Menu, rubber banding, grid, zoom, wire frame, rotate.
	demonstrate competence in the running and application of one graphics system or program;	This could be a 2 or a 3D graphics programme

GRADE DESCRIPTIONS

Grade descriptions are provided to give a general indication of the standards of achievement likely to have been shown by candidates awarded particular grades. The grade awarded will depend in practice upon the extent to which the candidate has met the assessment objectives overall and it might conceal weaknesses in one aspect of the examination which is balanced by above average performance in some other aspect.

Grade C

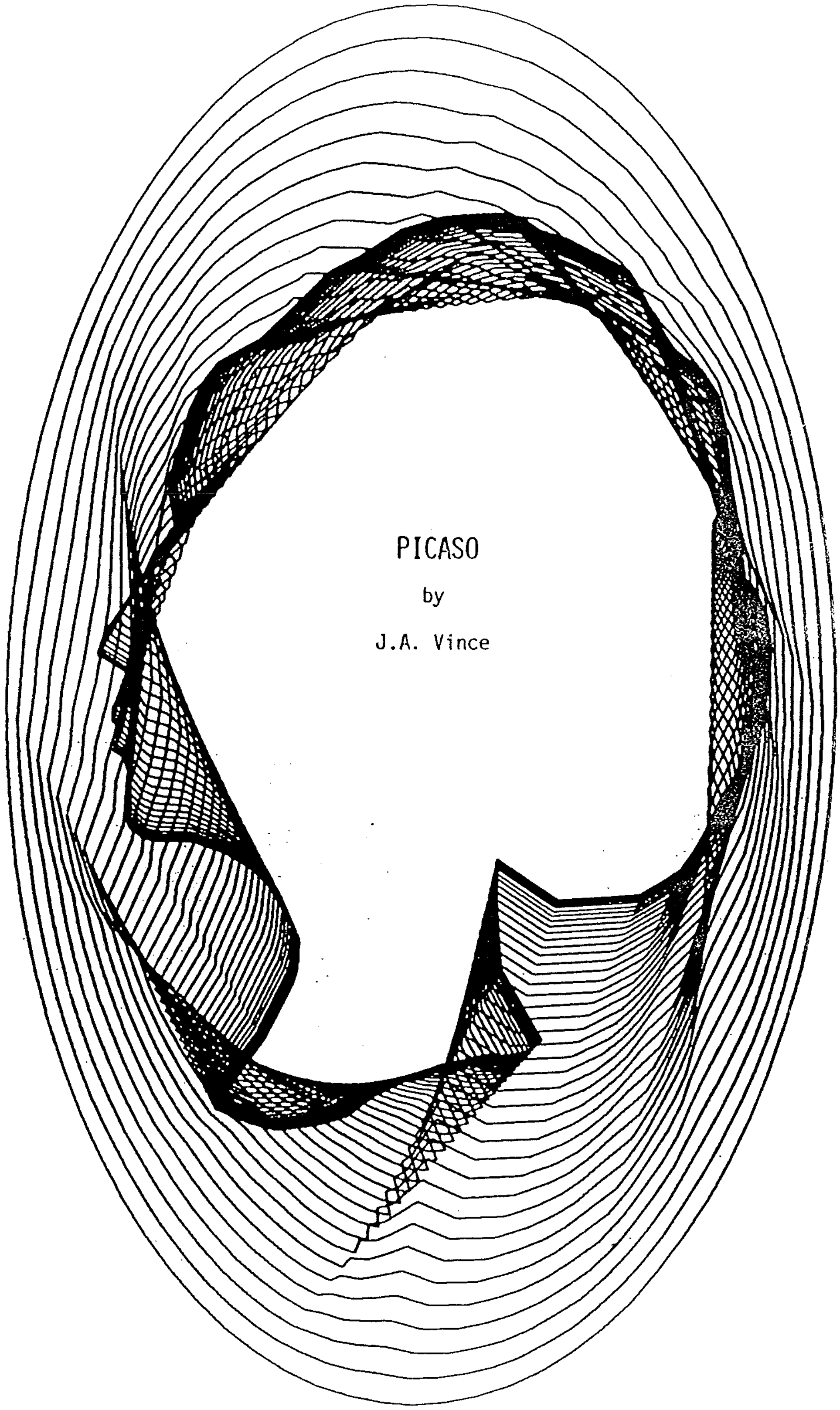
SKILLS

1 Design

The candidate will have identified a problem and a clear statement of the design brief. Investigation and analysis of the most important aspect will have led to the generation of a range of ideas as possible solutions to the problem. There will have been some evidence of first hand collection of relevant information and an application of knowledge of materials, components and constructions. The candidate's powers of discrimination will have enabled reasons to be given for the selection/rejection of those details considered in arriving at a preferred solution, and a valid evaluation will have been made on the basis of simple criteria.

2 Making

The candidate will have shown evidence of skilful working practices and sound construction in the material(s) used. When an artefact has been realised, fitting parts will locate well, the finished item will have been constructionally sound and functional. Where appropriate, suitable finishing techniques will have been used and 'finishes' will have been successfully applied.


PICASO
by
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Middlesex Polytechnic
Enfield Computing Centre

THE PICASO SYSTEM J.A. Vince	U10.2/A2

INDEX

1 INTRODUCTION

Picaso is a computer language designed to enable graphic peripherals to be used with the minimum of programming effort and skill. Although the system was initially designed for artists and designers, it includes extensive facilities that are relevant to mathematics and engineering.

The following sections describe *Picaso* to facilitate the implementation of the system, and illustrate the methodology of program design.

2 EXTERNAL REQUIREMENTS

2.1 SOFTWARE

The *Picaso* system is written in FORTRAN IV and consists entirely of FORTRAN subroutines and functions. These are normally held in a precompiled form as a library, and are referenced by FORTRAN programs or any other language permitted to operate in this mode.

The only way the system functions in a real-time mode, is for the original source program to be modified and recompiled. There is already one system that operates in this way and it appears to be quite successful.

Picaso was designed to drive a graph plotter, but will accept any device that can be driven by a command of the following form:

CALL SUBNME(X,Y,I)

where:

X,Y (REAL inches) is the coordinate to which the pen moves.

I (INTEGER) is the status of the pen.

- *I=2* the pen is down,
- *I=3* the pen is up,
- *I=-ve* establish a new origin at *X,Y*.

This command is equivalent to the *PLOT* subroutine supplied by CALCOMP in their plotting suite.

2.2 HARDWARE

The original *Picaso* system was implemented on a HONEYWELL-120 series digital computer with a CALCOMP-512 12" drum plotter. The memory size was 32K (6-bit words) with each REAL quantity requiring 9 words and each INTEGER quantity requiring 3 words. This is approximately equivalent to an 8-16K machine with a word length of 16 bits.

It is highly improbable that any one program will require every subroutine and function available in *Picaso* to be in memory at object run-time. Therefore, the memory requirement for a program depends entirely upon the number of geometric structures manipulated, and the commands employed. However reasonably complex programs may be run on small-memory machines.

Routines such as *PRINT,PUNCH,SHAPE,OBJECT,ARRAY1,ARRAY2 & ARRAY3* access a line-printer and a card-reader and the device numbers used are:

card-reader	2
printer	3
card-punch	5

3 SYSTEM STRUCTURE

3.1 SYSTEM FACILITIES

Picaso permits the user to work in 2 or 3 dimensions in the same program. It also enables the user to create, manipulate and analyse geometric structures before their realisation as a permanent visible image on a graph-plotter, visual-display or micro-film. Figure 3.1 illustrates in block-form the structure of *Picaso*.

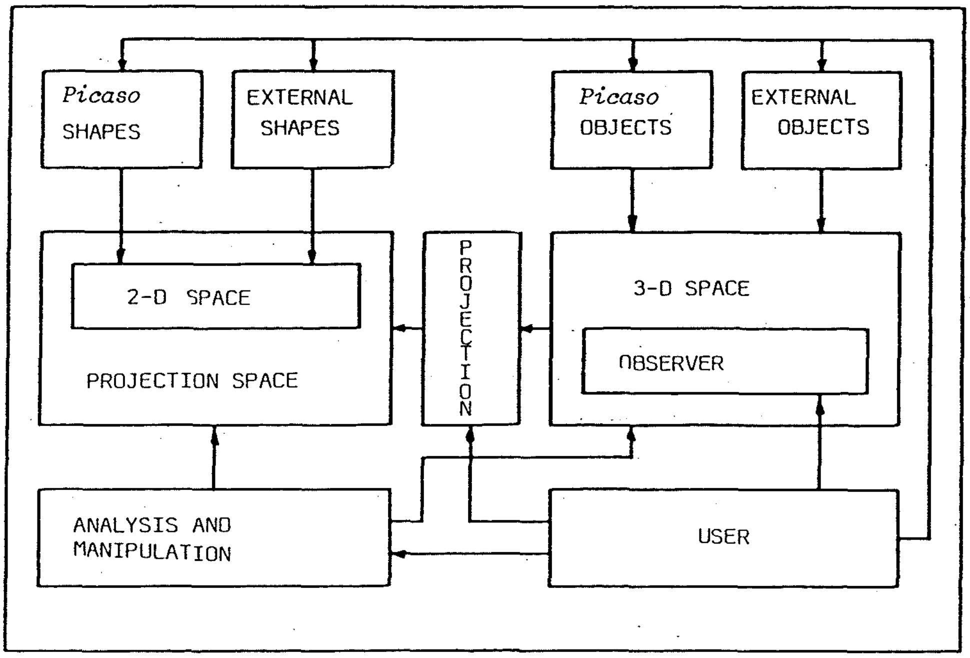


Figure 1

The user has control over every aspect of the system apart from communication areas that would normally only be available to the systems programming department. The following sub-sections describe the function of the system blocks.

3.2 THE OBSERVER

The observer is only relevant in the realisation of 3-D drawings and permits objects to be viewed from any position. His location and point under observation are established by the commands *EYE* or *FISHI* which also control the mode of projection. *EYE* creates conventional perspective drawings whilst *FISHI (Fish Eye)* creates a pseudo wide-angle effect.

3.2 THE OBSERVER (cont)

There is no prefered position for the observer, but the point under observation must be near to the objects under observation, otherwise nothing will be seen!

All 2-D drawings exist in the X-Y plane and the position of the observer is irrelevant.

3.3 2-D LIBRARY

The 2-D library contains an extensive range of shapes and contours including polygons, lines, ellipses, a face, an elephant etc.. Commands in this category store shapes in a data structre that can eventually be manipulated by other commands.
An example would be:

CALL POLYGN(P,1.0,6)

which stores in the REAL array *P* a six-sided polygon of radius *1.0* inch.

3.4 3-D LIBRARY

The 3-D library contains a range of objects such as cubes, pyramids and spheres etc.. These like 2-D shapes are stored in a REAL array and may be manipulated with equal ease.
An example would be:

CALL CUBE(C,1.0)

which stores in the REAL array *C* a regular *1.0* inch cube.

3.5 EXTERNAL SHAPES

Shapes not included in the 2-D library may be input via punched cards using the *SHAPE* command, but for other devices such as a tablet, keyboard and joy-stick special logic must be exployed to load data into the *Picaso* data structure.

3.6 EXTERNAL OBJECTS

Objects not included in the 3-D library may be input via punched cards using the *OBJECT* command, but for other devices, as explained in section 3.5, special logic is required.

3.7 2-D SPACE

2-D space is a conceptual space that holds *Picaso* shapes, permitting them to be manipulated, analysed and eventually displayed. The space conventions are shown in Figure 3.2 with the X-axis horizontal and the Y-axis vertical.

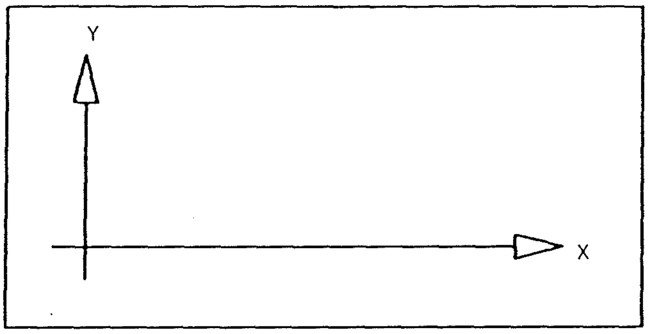


Figure 3.2

3.8 3-D SPACE

3-D space is a conceptual space that holds *Picaso* objects, permitting them to be manipulated, analysed and eventaully displayed. The space conventions are illustrated in Figure 3.3, and conform to the right-handed system in mathematical terms.

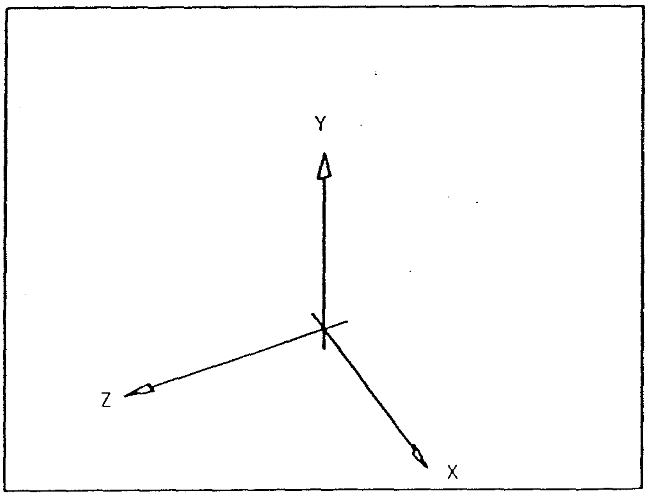


Figure 3.3

3.8 3-D SPACE (cont)

The realisation of perspective drawings is obtained by the mechanism of projecting onto a picture plane associated with the observer, as shown in Figure 3.4

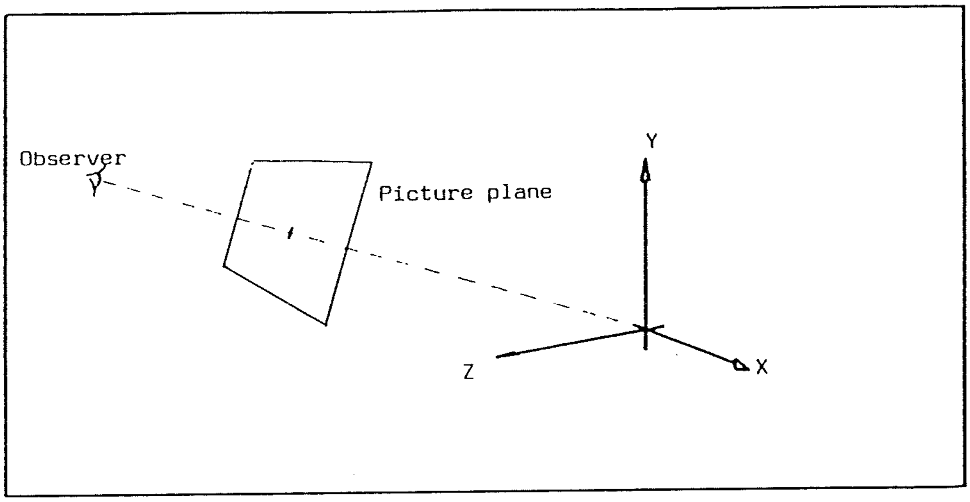


Figure 3.4

3.9 MODE OF PROJECTION

The mode of projection is only relevant to 3-D drawings. *EYE* creates conventional perspective drawings and *FISHI* produces a pseudo wide-angle projection.

3.10 PICTURE PLANE

The picture plane represents the final medium for representing all drawings. It is equivalent to the 2-D space and is used to generate perspective drawings from 3-D space.

3.11 ANALYSIS AND MANIPULATION

Shapes and objects may be analysed to determine various geometric and spatial properties, such as, the number of vertices or surfaces belonging to a structure. They may also be manipulated to change their size and position and alter other physical characteristics. Examples of these commands are:

3.11 ANALYSIS AND MANIPULATION (cont)

N=NPOINT(A,1)

this statement sets *N* to the number of points on the first contour of *A*.

CALL SIZE(A,2.0,0.0,0.0)

this statement doubles the size of *A* with respect to the origin.

4 COMMAND CATEGORIES

4.1 SYSTEM MODULARITY

Picaso is highly modular in that each subroutine and function is built upon standard logic blocks providing a high degree of integrity. Each subroutine or function also belongs to a specific category and these are now explained.

4.2 2-D LIBRARY

Supplies an extensive range of two-dimensional shapes and contours as explained in section 3.3.

4.3 3-D LIBRARY

Supplies an extensive range of three-dimensional objects and surfaces as explained in section 3.4.

4.4 SHAPE & OBJECT ANALYSIS

These commands return to the user geometric, spatial and topological information about shapes and objects.

4.5 SHAPE & OBJECT MANIPULATION

These commands permit the user to manipulate shapes and objects in space altering parameters such as, size, displacement, distortion etc..

4.6 SYSTEM COMMANDS

System commands are used to establish or alter important characteristics such as:

a) Initialisation,	*START*
b) Mode of projection,	*EYE & FISHI*
c) Distance of the picture plane,	*PLANE*
d) Position of the observer,	*EYE & FISHI*
e) Windowing,	*FRAME & WINDOW*
f) Origin location,	*ORIGIN*
g) Basic drawing command,	*PLIT*
h) Termination.	*FINISH*

4.7 SURFACE COMMANDS

These commands enable the user to create and observe a variety of surfaces in various projections.

4.8 2-D DRAWING COMMANDS

2-D drawing commands are used to realise single or groups of *Picaso* shapes.

4.9 3-D DRAWING COMMANDS

3-D drawing commands are used to realise single or groups of *Picaso* objects.

4.10 CONTOUR GENERATING FUNCTIONS

These functions supply in standard function form contours that may be combined to produce complex two, and three-dimensional trajectories in space.

4.11 VECTOR SUITE

The vector suite consists of a library with analytical and manipulative commands, and is compatible with other *Picaso* commands.

4.12 ARRAY HANDLING

To ensure that various implementations of *Picaso* remain compatible, a range of functions is available to initialise and reference INTEGER, REAL and LOGICAL arrays in one, two and three dimensions.

4.13 SPEICAL FUNCTIONS

These include useful functions that are not generallv available such as pseudo-random number generators.

4.14 SPECIAL EFFECTS

These include a variety of commands that create directly interesting graphic effects for design purposes.

4.15 OUTPUT COMMANDS

These are commands that generate external representations of *Picaso* structure on punched cards or the line-printer.

5 DATA STRUCTURE

Picaso shapes and objects are stored in REAL one-dimensional arrays with the following structures:

5.1 2-D STRUCTURE

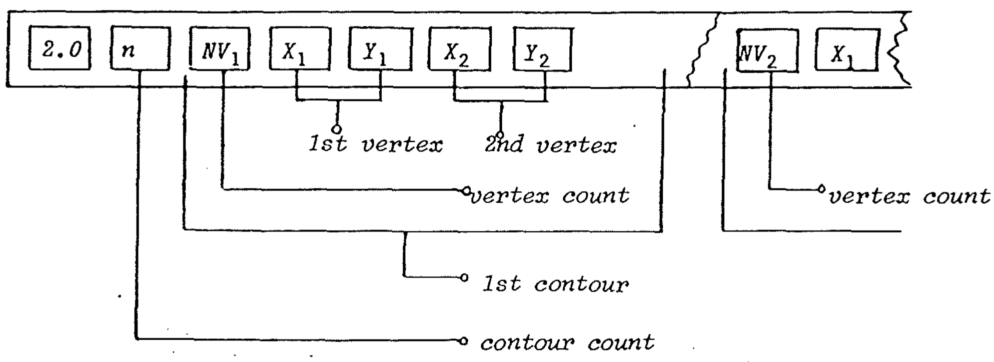
A *Picaso* shape consists of a number of open or closed contours that are created from a series of vertices connected by straight lines. The data structure demands that:

a) Each vertex requires 2 words (X & Y).

b) Each contour requires 1 word for the vertex-count.

c) Each shape requires 1 word for the contour-count.

d) Each shape requires 1 word for the number of spatial dimensions (2).



The total memory requirement can be expressed by the following expression:

$$\text{Memory} = 2 + \sum_{i=1,n} (1+2*NV_i)$$

where n is the number of contours, and

NV is the number of vertices in the i^{th} contour.

5.2 3-D STRUCTURE

A *Picaso* object may consist of a number of surfaces, or a number of open or closed contours that are created from a series of vertices connected by straight lines. The data structure demands that:

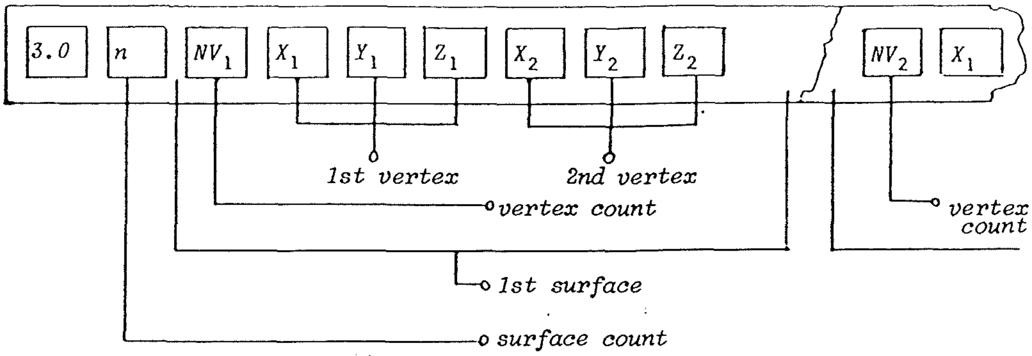
a) Each vertex requires 3 words (X,Y & Z).

b) Each contour or surface requires 1 word for the vertex count.

c) Each object requires 1 word for the contour or surface count.

d) Each object requires 1 word for the number of spatial dimensions (3).

5.2 3-D STRUCTURE (cont)



The total memory requirement can be expressed by the following expression:

Memory = $2 + \sum_{i=1,n} (1+3*NV_i)$

where n is the number of contours or surfaces, and

NV is the number of vertices in the i^{th} contour or surface.

6 COMMUNICATION AREAS

At present there are four communication areas and they are held in LABELLED COMMON. These are now described in details to assist the implementation of *Picaso* and the design of further subroutines.

6.1 PCLBØ1

PCLBØ1 labels an array that is used to hold a *Picaso* shape, which may be used by *PLIT* to *window* drawings on the picture plane. The shape is established by *WINDOW* and *PLIT* calls *CLIP* to *clip* line segments against the *window* shape. It is not essential that this mode of operation has to be established, but represents a system option.

When the first element of the array is zero, *PLIT* automatically assumes that there is no *window*, but when a shape has been established by *WINDOW*, the first element is set to 2.0 and *PLIT* *clips* line segments against the shape. The array's first element is set to zero by the subroutine *START*.

6.2 PCLBØ2

PCLBØ2 labels four variables and two arrays used to hold minimum and maximum X and Y limits of a rectangular frame that may be used to *window* drawings on the picture plane. The labelled block is as follows:

XMIN (REAL inches) minimum X-value.

XMAX (REAL inches) maximum X-value.

YMIN (REAL inches) minimum Y-value.

YMAX (REAL inches) maximum Y-value.

WX (REAL array) holds the X-values of the frame in the following sequence:
XMAX, XMIN, XMIN, XMAX, XMAX.

WY (REAL array) holds the Y-values of the frame in the following sequence:
YMIN, YMIN, YMAX, YMAX, YMIN.

WX & WY are dimensioned 5.

The rectangle held by FRAME is shown in Figure 6.2.

6.2 PCLBØ2 (cont)

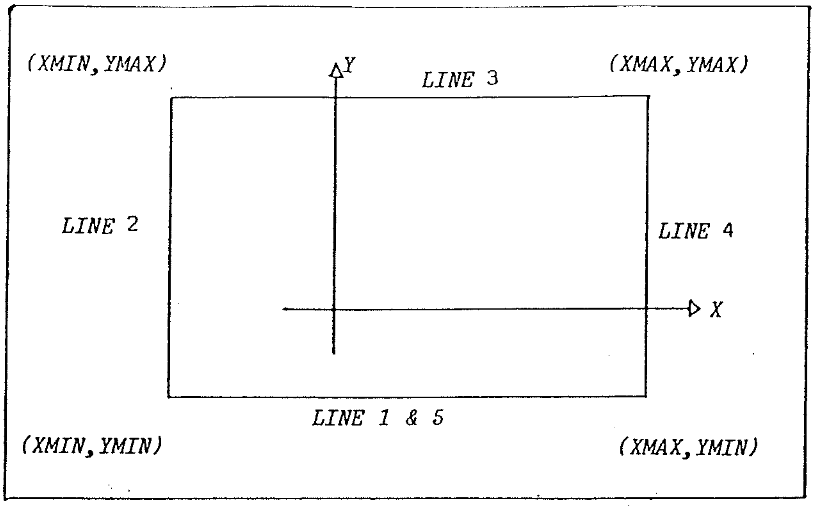


Figure 6.2

and as can be seen from the diagram, consists of five lines which are held in the arrays *WX* and *WY*.

A default frame may be created by *START* which must initialise the four variables and the two arrays; subsequent rectangles are then established by *FRAME*.

6.3 PCLBØ3

PCLBØ3 consists of 16 variables used in the perspective transformation algorithm. They are now listed in their correct sequence.

PICXF (REAL inches) is the X-coordinate of the focal point.
PICYF (REAL inches) is the Y-coordinate of the focal point.
PICZF (REAL inches) is the Z-coordinate of the focal point
PICXE (REAL inches) is the X-coordinate of the observer.
PICYE (REAL inches) is the Y-coordinate of the observer.
PICZE (REAL inches) is the Z-coordinate of the observer.
PICFR (REAL inches) is the radius of the fish-eye lens.
PICTY (INTEGER) is the type of perspective
=1 natural
=2 pseudo-wide-angle.

6.3 PCLBØ3 (cont)

PICSX (REAL) sine of rotation in the X-Z plane.

PICCX (REAL) cosine of rotation in the X-Z plane.

PICSY (REAL) sine of rotation in the Y-Z plane.

PICCY (REAL) cosine of rotation in the Y-Z plane.

PICX (REAL inches) is a transformed X-coordinate.

PICY (REAL inches) is a transformed Y-coordinate.

PICZ (REAL inches) is a transformed Z-coordinate.

PICPP (REAL inches) is the distance of the picture plane from the observer.

6.4 PCLBØ4

PCLBØ4 is a communication area for the contouring programs *MAP2D* and *MAP3D* and their scanning routines *SCAN2D* and *SCAN3D*.

The block layout is as follows:

OPCONT (LOGICAL) is set .TRUE. for open contours.

FRSTPNT (LOGICAL) is set .TRUE. for the first point.

LASTPNT (LOGICAL) is set .TRUE. for the last point.

ROWA (INTEGER) is a row value.

COLA (INTEGER) is a solumn value.

H (REAL) is the contour height.

S (REAL) is the height scaling factor.

XS,YS,ZS (REAL inches) is the degree of shift applied to the map.

SC (REAL) is the degree of enlargment or reduction.

7 SYSTEM COMMANDS

This group of commands perform different functions for individual implementations, for example, screen refreshing commands are unecessary for graph plotters and paper advancing is unecessary for graphic displays. However, for the sake of compatibility it is advisable that the command names are retained even though they may perform different functions.

7.1 START

START is a subroutine to initialise default values for variables in the communication areas, these are:

PICPP = 10.0" (distance of the picture plane)

XMIN
XMAX
YMIN
YMAX
WX & WY } (frame for windowing)

Plotting systems using *CALCOMP* software would also include the *CALL PLOTS* statement to establish the plotting buffers.

Graphic display systems might clear the screen before drawing commences.

When Picaso shapes are being used to window, the first element of the array held in *PCLBØ1* should be set to 0.0 to imply that there is no window.

7.2 ORIGIN

ORIGIN alters the position of the Cartesean origin on the drawing medium. It is actually a call on the *CALCOMP* statement *PLOT* with arguments:

(X,Y,-3)

where *X & Y* are the coordinates of the new origin relative to the existing origin.

If the new origin is not within the rectangular bounds of *FRAME*, various actions can result depending upon the logic of *FRAME*, which is adjustable by the system's programmer.

7.3 EYE

EYE is only required for 3-D drawings as it establishes the position and focal point of the observer. The command is:

CALL EYE(XE,YE,ZE,XF,YF,ZF)

where:

XE,YE,ZE are the coordinates of the observer, and

XF,YF,ZF are the coordinates of the focal point.

The observer may be located anywhere in space, as long as he looks towards the scene to be drawn.

When *EYE* is called, sines and cosines of angles are evaluated and stored in *PCLBØ3*, which is subsequently referenced by the perspective transformation algorithm *PERSP*.

7.4 FISHI

FISHI is identical to *EYE* apart from the inclusion of a seventh argument *R*.

CALL FISHI(XE,YE,ZE,XF,YF,ZF,R)

where *R* is the radius of a circular lens to create pseudo-wide-angle effects. The magnitude of *R* will normally be in the range of 1.0 to 10.0.

FISHI also sets *PICTY=2* (*PCLBØ3*) whereas
EYE sets *PICTY=1*.

7.5 PLANE

PLANE alters the distance between the picture plane and the observer by changing the value of *PICPP* in *PCLB03*. This should be set to a value equal to the viewing distance of the final drawing, i.e. something in the order of 10.0". If the system uses a version of DRAW3D which clips on the picture plane, (see section 9.2) altering this distance dynamically creates progressive cross-sections of objects.

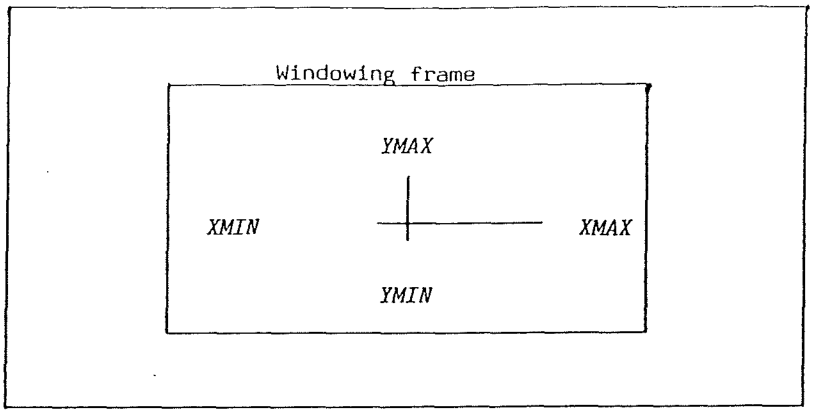
7.6 FRAME

FRAME establishes a rectangular boundary for drawings on the final media. It has four arguments:

XMIN,XMAX,YMIN,YMAX which

are held in the labelled-common block *PCLB02*.

7.6 FRAME (cont)



Any call upon *PLIT* will only generate drawings inside this boundary, clipping line segments against the four lines forming the rectangle.

The logic of *FRAME* may be altered to suit the individual needs of the user, but this should only be necessary to cope with changes of origin. For example, with a drum plotter, one wishes to avoid driving the pen beyond the width of the drum, therefore, origin changes should *not* be allowed beyond *YMIN* or *YMAX* but *could* be allowed to go beyond *XMAX*.

7.7. WINDOW

WINDOW establishes a complex *Picaso* shape that *windows* all final drawings. This would be used instead of *FRAME* when windows of unusual shapes were required, and when this mode of drawing is operational, one must ensure that the correct version of *PLIT* is used (i.e. the version that calls *CLIP*).

WINDOW has one argument which is the name of a *Picaso* shape, however, when the *window* shape is to be cancelled, *WINDOW* must be called with *0.0* as the argument.

CALL WINDOW (0.0)

7.8 PLIT

PLIT is a fundamental drawing command of *Picaso* and has arguments:

(X,Y,PEN) where:

X,Y (REAL inches) are the coordinates to which the pen moves.

PEN (INTEGER) is the status of the pen.

7.8 PLIT (cont)

PEN = 2 pen down,

PEN = 3 pen up,

PEN = -ve origin change.

If windowing is not required, the following subroutine should be employed:

```
SUBROUTINE PLIT (X,Y,I)
CALL PLOT (X,Y,I)
RETURN
END
```

where *PLOT* is the standard *CALCOMP* subroutine.

When windowing is required, there exists a version of *PLIT* which draws within the rectangular boundary created by *FRAME* and another which draws within the *Picaso* shape boundary established by *WINDOW.*

For the majority of work a rectangular frame is sufficient and also avoids the time and core overhead introduced by using *CLIP.*

7.9 FINISH

CALCOMP software requires that the plotter buffers are emptied before the program terminates, therefore, *FINISH* performs this operation by calling *PLOT* as follows;

CALL PLOT (X,-Y,999) which

1. moves the pen *X* inches to protect the last drawing,
2. moves the pen *-Y* inches to bring the pen back to the edge of the drum. (The value of Y would be the width of the drum), and
3. empties the buffers.

FINISH has one argument, *(X)* which is the number of inches the pen moves to protect the last drawing.

8 ARRAY HANDLING

8.1 COMMUNICATION OF ARRAYS

The majority of *Picaso* commands require that an array is supplied as an argument for a subroutine call, and as the size of the array is not known by the subroutine it is left undimensioned. For example the following notation is always employed:

```
SUBROUTINE SUBNME (ARRAY,.......)
DIMENSION ARRAY(1)
..
...
..
RETURN
END
```

8.2 ARRAY MANIPULATION

One, two and three-dimensional arrays are all treated as one-dimensional arrays and subscript evaluation is performed by the *Picaso* functions:

GET1
GET2 get a REAL number from an array,
GET3

IGET1
IGET2 get an INTEGER number from an array,
IGET3

LGET1
LGET2 get a LOGICAL number from an array,
LGET3

which retrieve data and the following subroutines which load data:

PUT1
PUT2 put a REAL number into an array,
PUT3

IPUT1
IPUT2 put an INTEGER number into an array,
IPUT3

LPUT1
LPUT2 put a LOGICAL state into an array,
LPUT3

8.2 ARRAY MANIPULATION (cont)

Array searching is performed by the following subroutines:

$\left.\begin{array}{l}\textit{FIND1}\\ \textit{FIND2}\\ \textit{FIND3}\end{array}\right\}$ search for a REAL value,

$\left.\begin{array}{l}\textit{IFIND1}\\ \textit{IFIND2}\\ \textit{IFIND3}\end{array}\right\}$ search for an INTEGER value.

8.3 SUBSCRIPT CHECKING

Subscript boundary checking is performed by the previous commands during array manipulation, but not when arrays are initialised by other routines. The user must always ensure that arrays are correctly declared in the main calling program.

9 WINDOWING AND CLIPPING

9.1 WINDOWING

As mentioned earlier, *PLIT* may function in one of three modes:

i) Subroutine *PLIT* directly calls *PLOT* and performs no windowing, unless *PLOT* includes the necessary logic or exists in the hardware.

ii) Subroutine *PLIT* windows line segments against the rectangular window established by *FRAME*.

iii) Subroutine *PLIT* windows line segments against any *Picaso* shape established by *WINDOW*.

Therefore any one of these versions may be implemented, and perhaps where suitable facilities exist, the user could be permitted to access any version.

9.2 CLIPPING

Clipping is the process of removing detail from a 3-D scene that exists on the observers side of the picture plane. A version of *DRAW3D* includes *clipping* logic to remove this detail and may be implemented in preference to the standard version.

Figure 9.1 illustrates the effect with a cone.

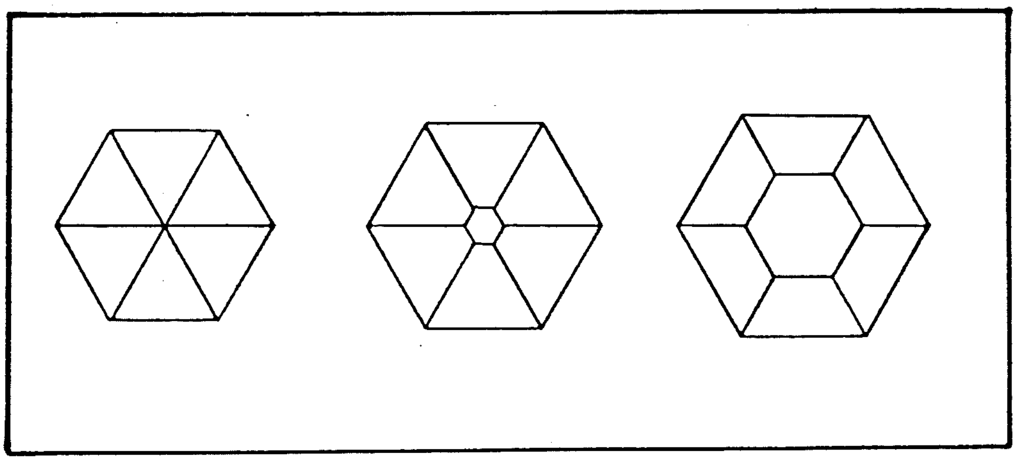


Figure 9.1

1C ERROR DETECTION

Where it is thought necessary, *Picaso* subroutines and functions include traps to isolate errors that suggest major faults in program design. The error subroutine is called with an INTEGER type number which is displayed on the line-printer. The *Picaso* reference manual lists the error messages in section 17. Normally, a subroutine should not contain a *STOP* statement, therefore, to curtail execution of a program on detecting an error condition, *ERROR* should call the system exit routine.

11 PROGRAM DESIGN

11.1 ARRAY DECLARATION

All *Picaso* shapes and objects are held in REAL one-dimensional arrays which must be declared on a *DIMENSION* statement as in any standard FORTRAN program. The size of the array can be calculated by the expression included in the *Picaso* reference manual or by the formula shown in sections 5.1 and 5.2.

11.2 ORIGIN LOCATION

The location of the origin is extremely important in any type of drawing whether it be two or three-dimensional in nature. *Picaso* shapes tend to have the origin located at their centres, and when the shape is drawn, the shape's origin is located at the origin established on the drawing surface, unless a degree of shift is implied. The location of the origin on the drawing surface determines the initial position of any shape, and therefore its position must be chosen with some consideration to the graphic scene required.

In 3-D work, the point in space under direct observation is located at the origin on the drawing surface, therefore, the location of the origin must be carefully placed if a complete scene is to be drawn.

11.3 2-D DRAWING

The following program illustrates how a horse may be drawn at half its original size.

```
DIMENSION H(237)
CALL START
CALL ORIGIN(5.0,5.5)
CALL HORSE(H)
CALL DRAW(H,0.5,0.0,0.0)
CALL FINISH(5.0)
STOP
END
```

The drawing is shown in Figure 11.1

11.3 2-D DRAWING (cont)

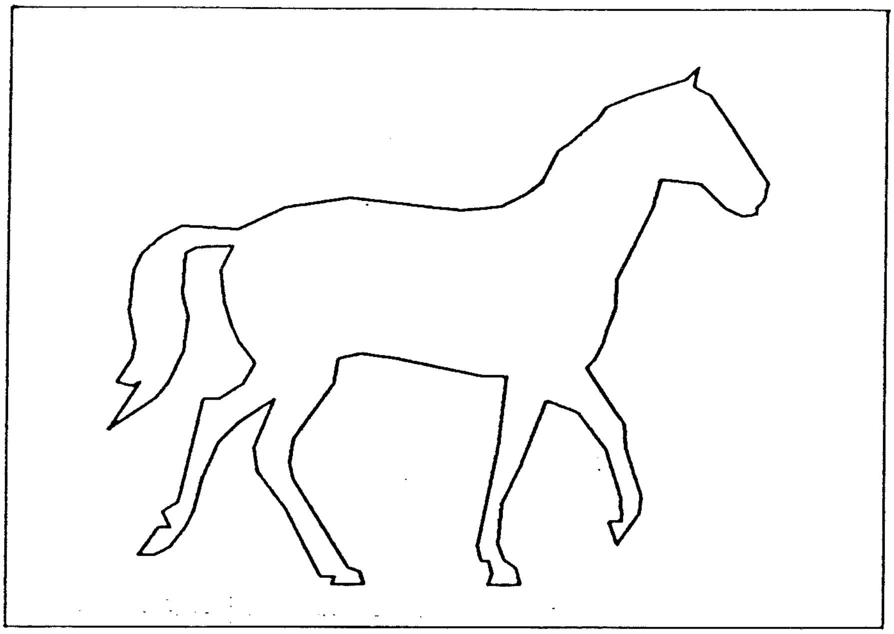


Figure 11.1

11.4 3-D DRAWING

This example draws out a grid of boxes in wide-angle.

```
DIMENSION B(98)
CALL START
CALL ORIGIN(5.0,5.5)
CALL FISHI(5.5,5.5,10.0,5.5,5.5,0.0,4.0)
CALL BOX(B,2.0,2.0,4.0)
CALL GRID3D(B,1.0,0.0,0.0,0.0,4,3.0,4,3.0,-1)
CALL FINISH(6.0)
STOP
END
```

The output of this program is shown in Figure 11.2

11.4 3-D DRAWING (cont)

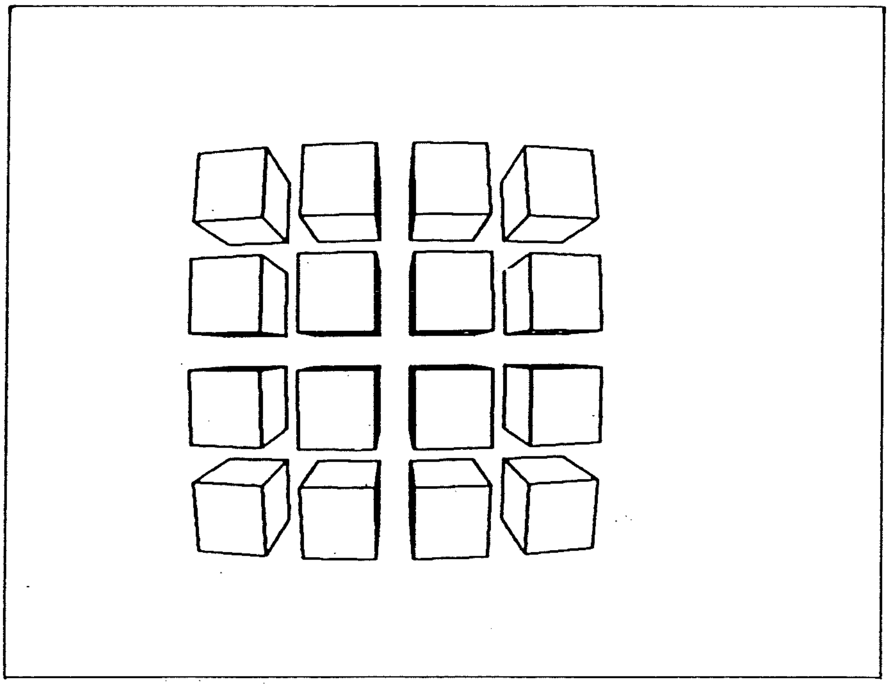


Figure 11.2

11.5 SURFACES

Picaso permits many surfaces to be drawn, and probably the most effective is *SURFAC*, and therefore this has been chosen for the example.

A damped sinewave will generate the surface and is created by multiplying a line by a sinusoid using *ASMDSH*.

11.5 SURFACES (cont)

```
DIMENSION A(7),B(63),W(60),OV(60),UN(60)
CALL START
CALL ORIGIN(2.0,5.0)
CALL LINE(A,1.0,1.0,1.0,0.0,2)
CALL SINE(B,1.0,2.0,90.0,720.0,30,0.0,1.0)
CALL ASMDSH(A,1,B,1,B,3)
CALL SURFAC(B,4.0,60,4.0,30,30.0,2.0,2.0,2.0,W,OV,UN,0.0,0.0)
CALL FINISH(8.0)
STOP
END
```

The output to this program is shown in Figure 11.3

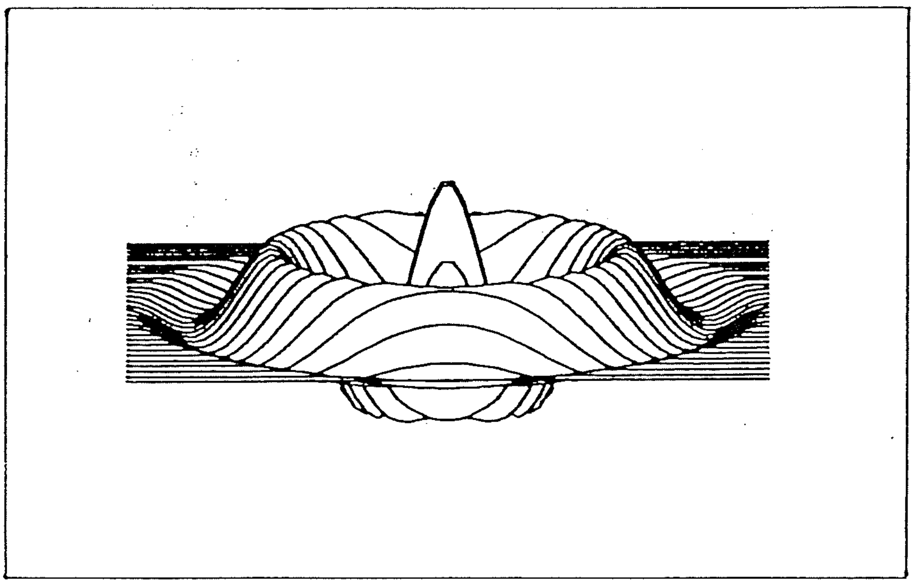


Figure 11.3

12 PROGRAM FAULT DIAGNOSIS

It is difficult to give specific procedures to isolate program faults, but the following steps should be followed when an undefined error occurs.

i) Ensure that all arrays have been correctly defined in terms of type and size.

ii) Verify the number, sequence and type of all arguments.

iii) Establish that structures have been declared and that output commands are included.

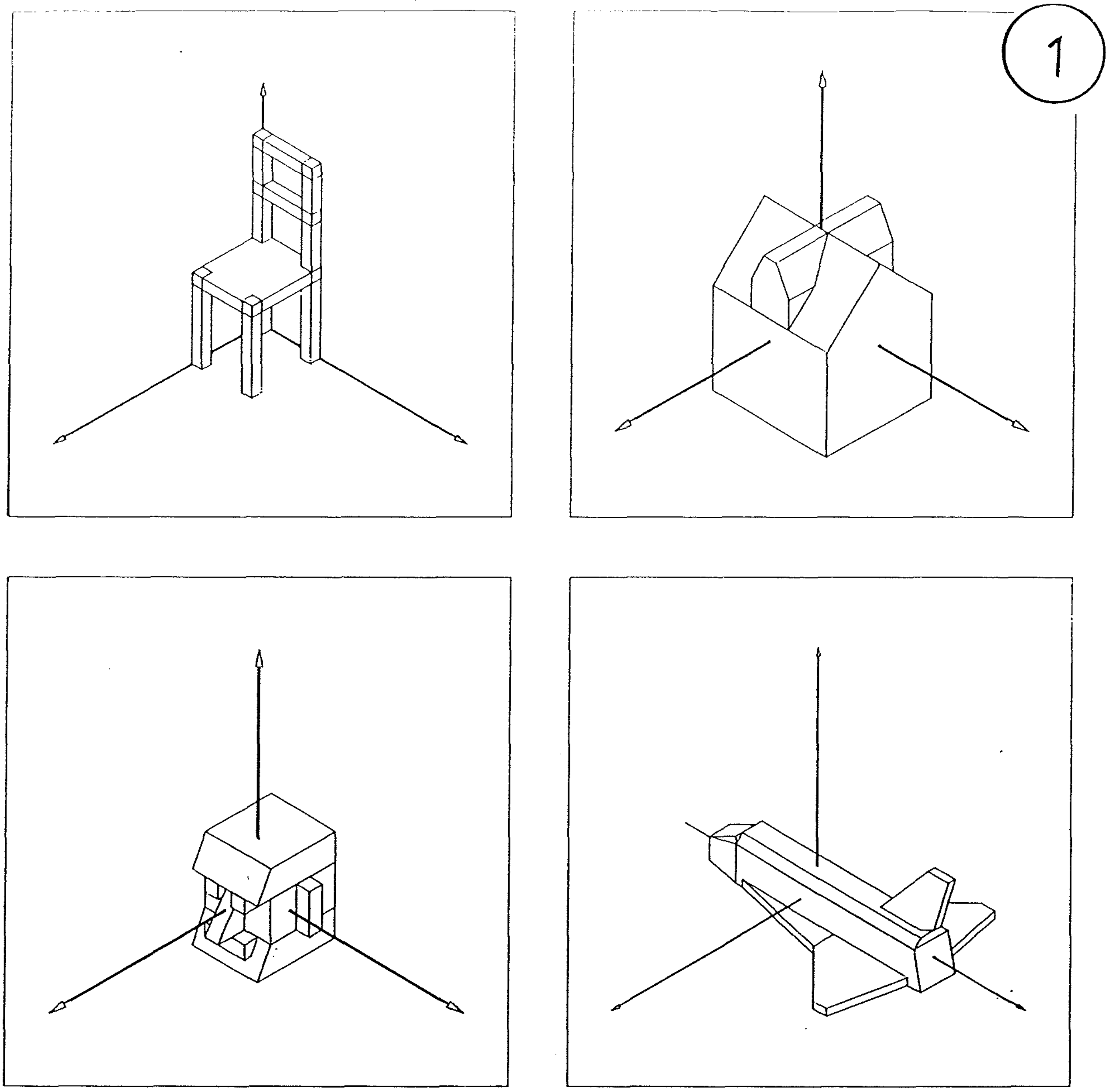
iv) For 3-D work ensure that the observer is looking in the correct direction.

v) Use the *PRINT* command to dump the contents of structures.

APPENDIX 2

OWN INSTRUCTIONAL MATERIAL

Contents Appendix 2 Own Instructional Material

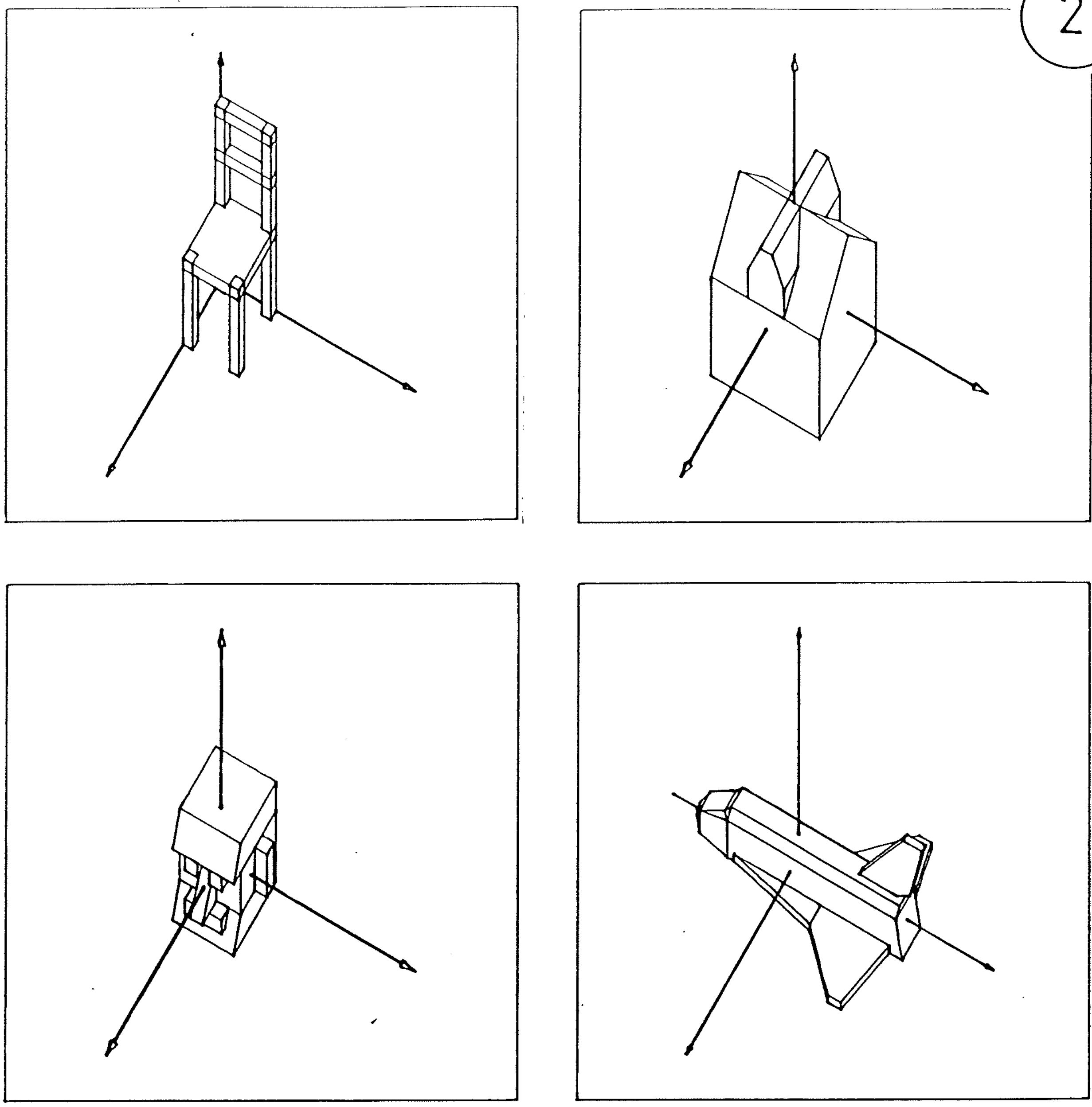


Notes to memorise

1. Note that all horizontal edges of the above objects must be drawn at an angle of 30 degrees to the horizontal.

2. isometric views can be drawn without instruments on isometric grid paper, or isometric dot paper.

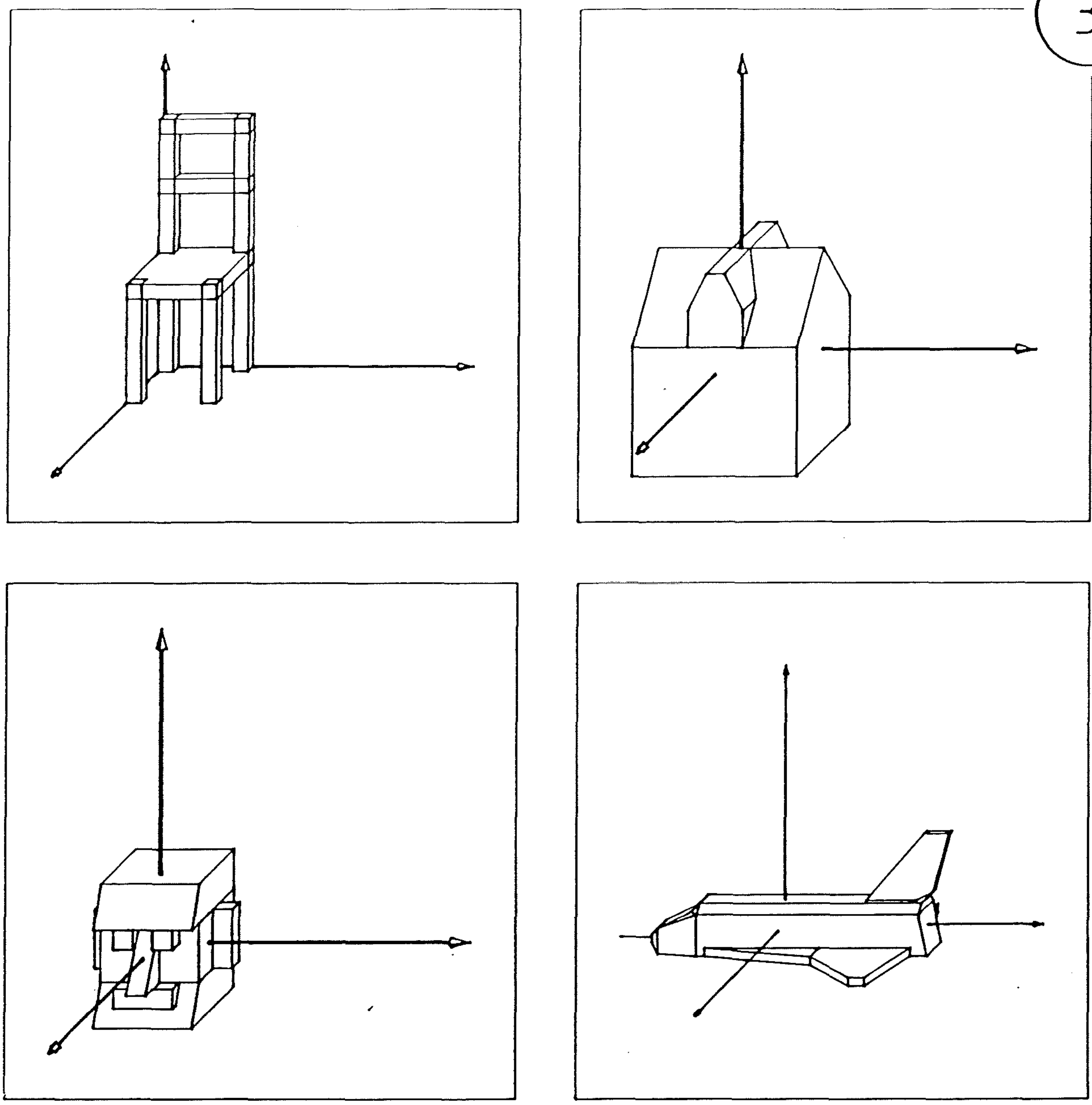
Pictorial views: Isometric



Notes to memorise

1. All top facing horizontal surfaces are drawn true to shape.
2. The objects are drawn at an angle of 30 and 60 degrees to the paper horizontal.
3. Height measurements are foreshortened, usually to 3/4 scale.

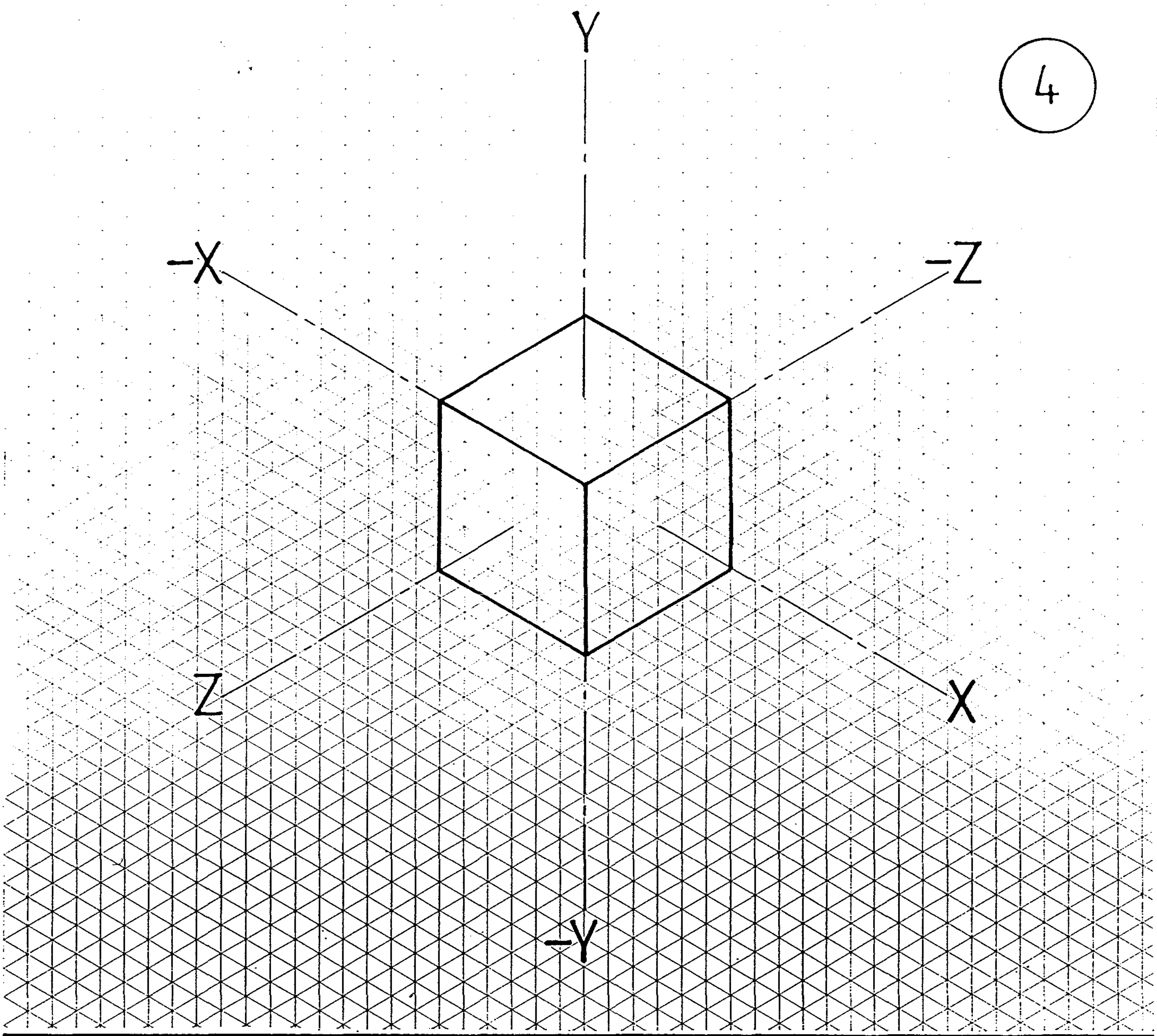
Pictorial views: Planometric



Notes to memorise

1. All front facing vertical surfaces are drawn true to shape.
2. Depth measurements are foreshortened – usually by a half.
3. In the above examples the oblique angle is 45.0 degrees.

Pictorial views: Oblique



Technical Words

Cube   A cube is a special sort of box with square shaped sides.

X,Y,Z   Things are measured in three directions at right angles to each other. People get easily mixed up so in technical work we call the directions X,Y,Z.

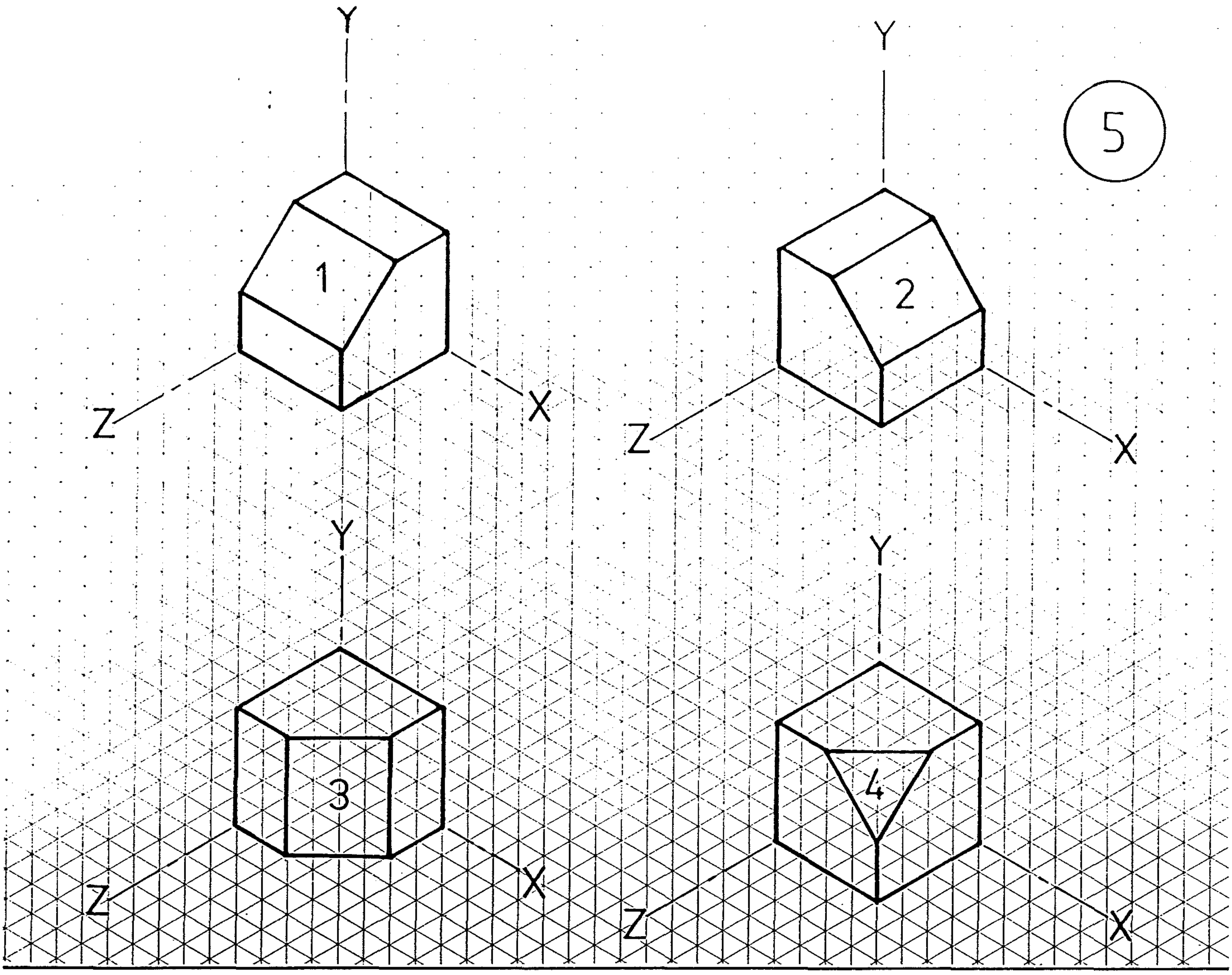
-X,-Y,-Z   If you looked at the cube from the -XYZ directions you would be able to see the hidden sides.

Instructions

Copy   Copy the drawing of the cube and the XYZ lines.

Colour   Colour your drawing so the top of the cube is yellow. The side facing the X direction is blue. Colour the other side red.

XYZ Colouring Idea 1



Technical Note

Sloping Surfaces

A surface slopes if it is neither horizontal or vertical. The four ways in which a surface can be said to slope are shown above.

Colouring Sloping Surfaces

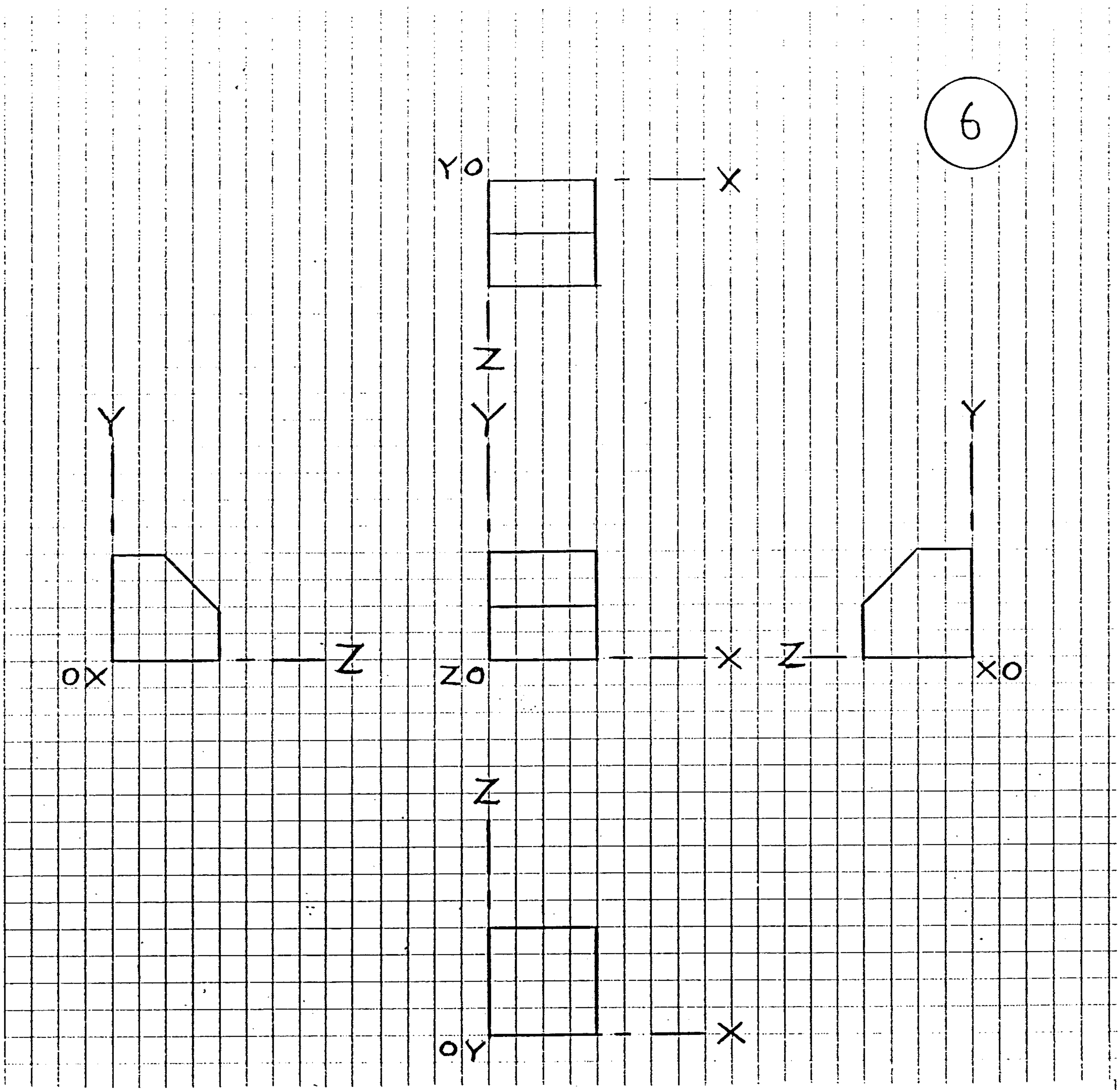
A horizontal or vertical surface can only be seen from one of the XYZ directions. Sloping surfaces can be seen from more than one direction, and will require more than one colour. Example 1 above contains a surface that will require colouring yellow and red.

Instructions

1. Copy   Copy the drawings above onto A4 3D paper.

2. Colour   Colour your drawing using the 'XYZ Colouring Idea 2'.
NOTE colour evenly all over the surfaces - example 1 will be orange after colouring with yellow and red.

XYZ COLOURING IDEA 2

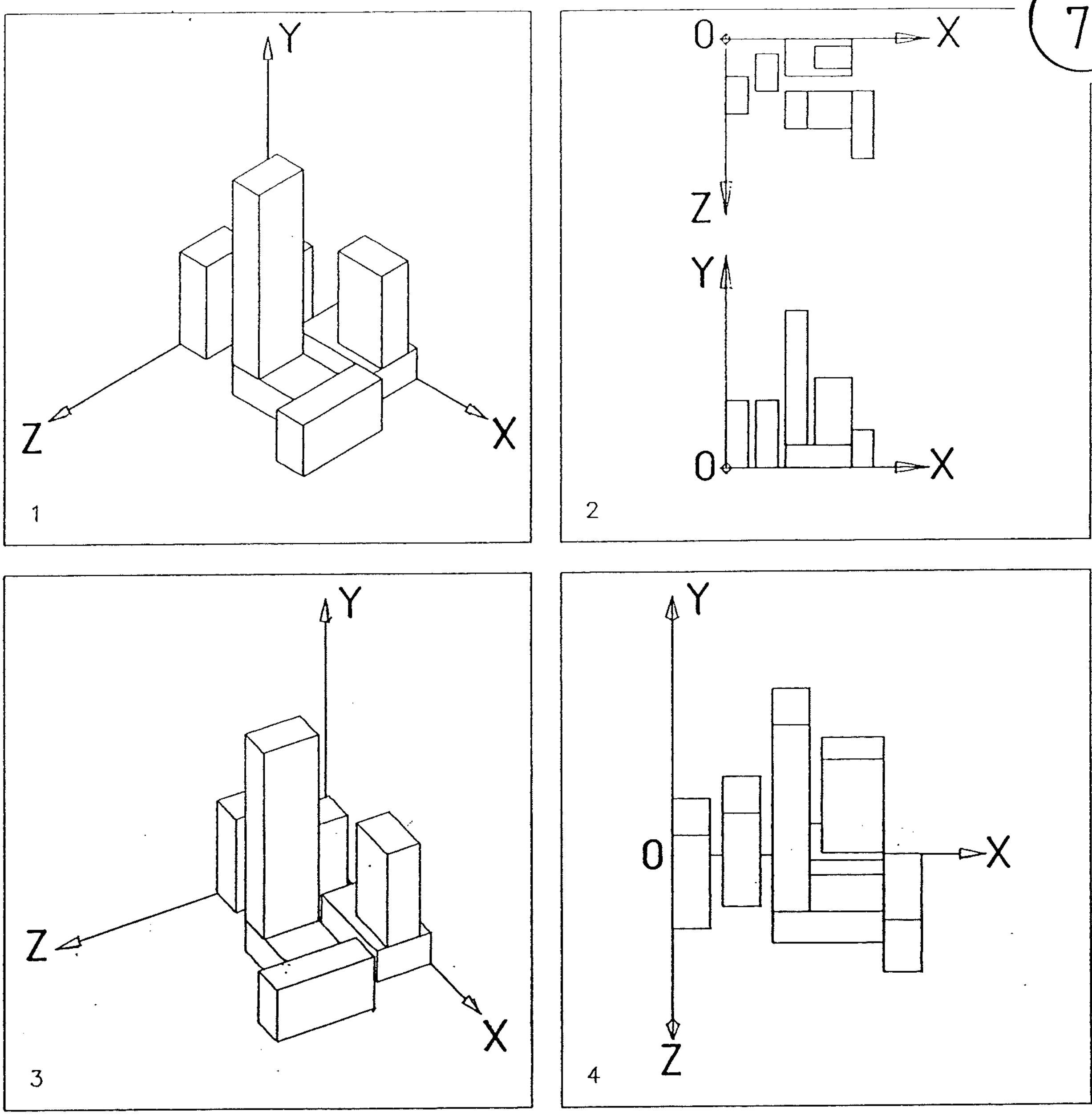


The above drawing is a five view drawing of example 1 on the other page. Study the way the axes are labeled, notice that the **origin** is included.

In the top view the Y axis is labeled YO, this is because the view is drawn looking from the Y direction towards the origin. The underneath or bottom view is labeled OY because the view is from the origin towards the Y axis. **Note** to save space the negative axes are not drawn.

Exercises

1. Copy the above drawing and colour it using the colouring idea.
2. Draw a similar drawing of one of the other examples on the other page and colour it using the colouring idea. .



City block project

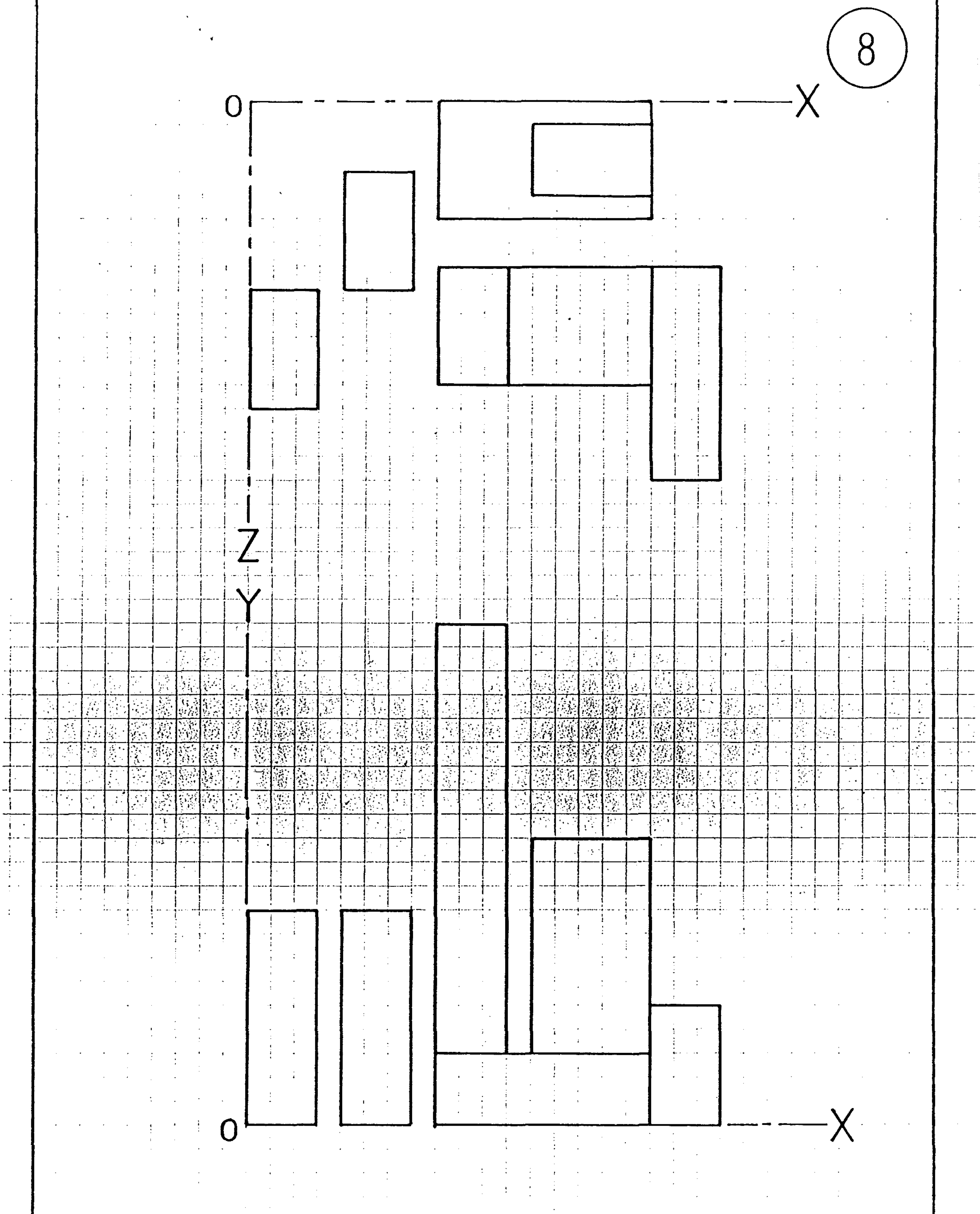
The drawings above are of a model city block. The model is made of seven cuboids. On the opposite page is a large two–view drawing that has been drawn on squared paper, this drawing has been used to make the model.

Instructions

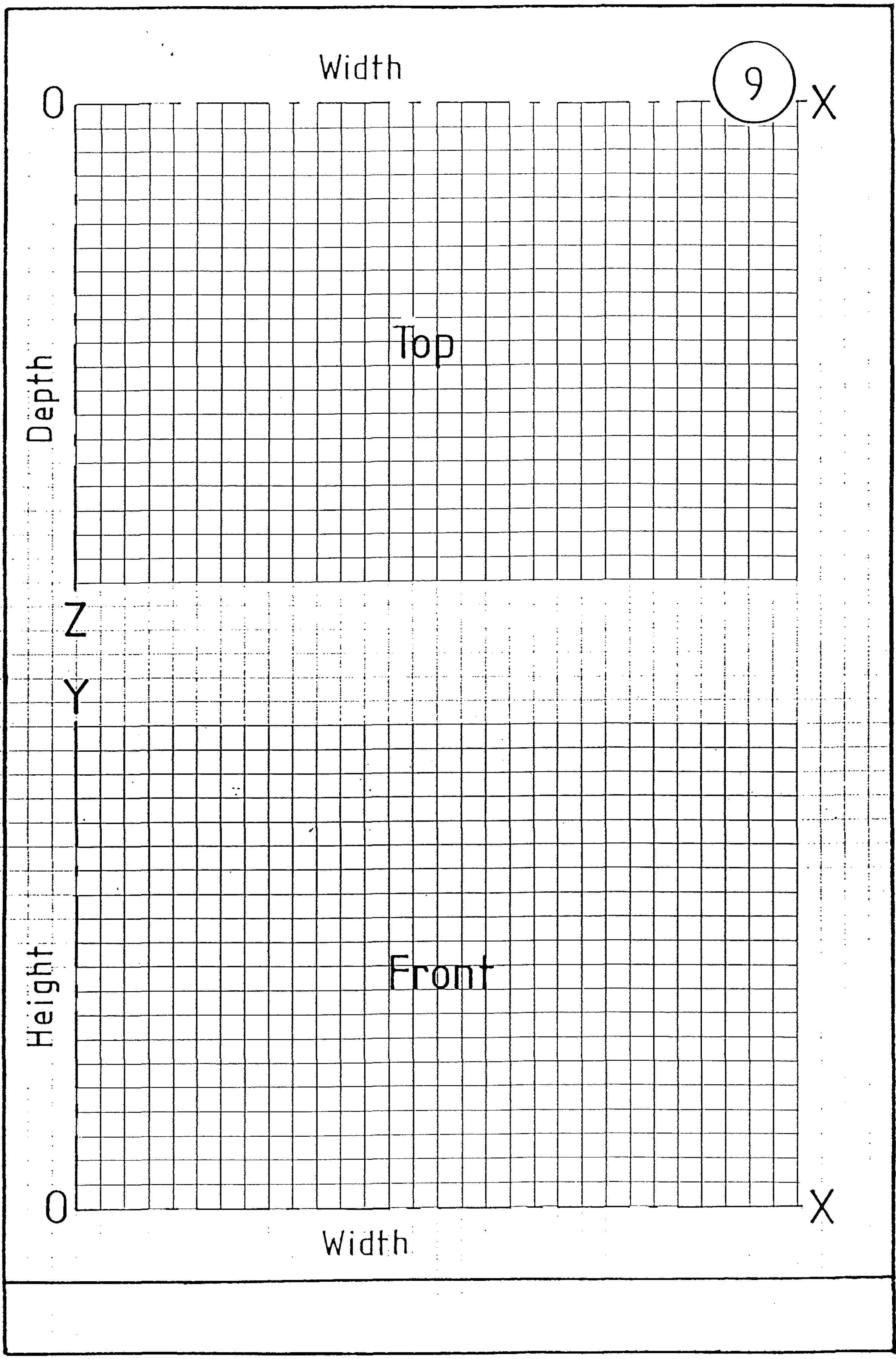
1. Using a set of cuboids make a model of the city block exactly like the example above. Ask your teacher to check your construction.

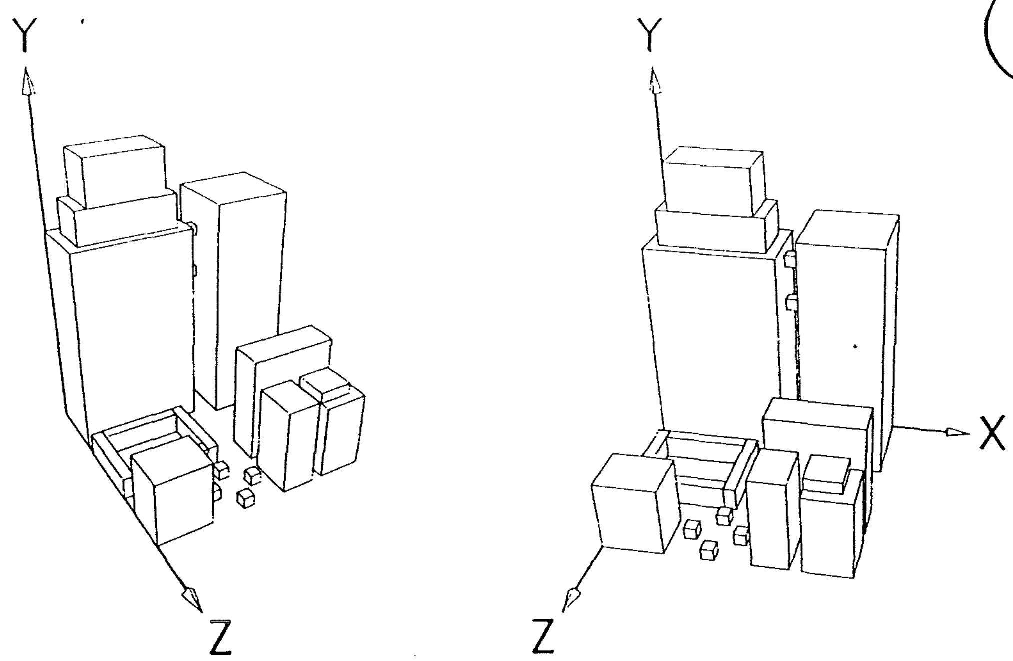
2. Make your own city block using the set of cuboids.

3. Make a two–view drawing of your design include a border and a title box. Use A4 squared paper.



City project	Name	Tutor group	Scale	Date


9
Width
0
X
Top
Depth
Z
Y
Front
Height
0
X
Width



Instructions

1. Design a part of a city that occupies a square plot of land. The buildings must consist of cuboids for "City Unit 1". You may have some open areas, minor sports facilites, and pathways.

Notes Limit your design to a square of side 100 metres. The maximum height of any building 150 metres.

Use Use square grid paper A3 size. Draw two views plan and front elevation in projection. Study the example very carefully and note that hidden detail is required.

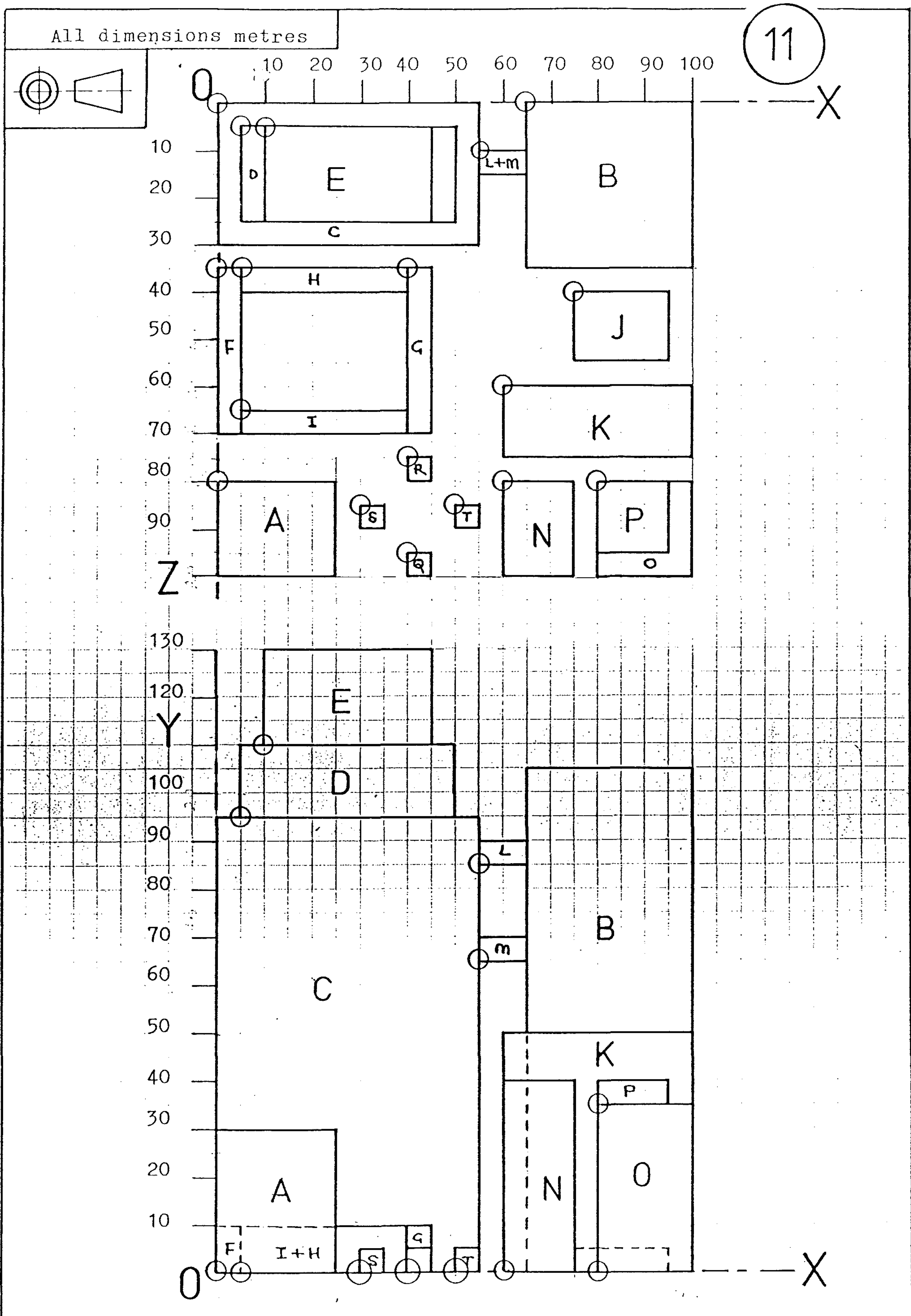
*** If in doubt ask!

2. Ask your teacher to check your design.

Preparation of data for the computer

1. Carefully scale your views - study the example.
2. Label each cuboid A,B,C,D...... in both views!
3. Considering each cuboid decide which corner is nearest to the origin,identify it with a circle in both views.
4. Ask for a cuboid data sheet. Complete the data sheet very carefully - if in doubt ask.

City Unit 1



CITY UNIT	SCALE 1:1000	G. EDWARDS	3/26

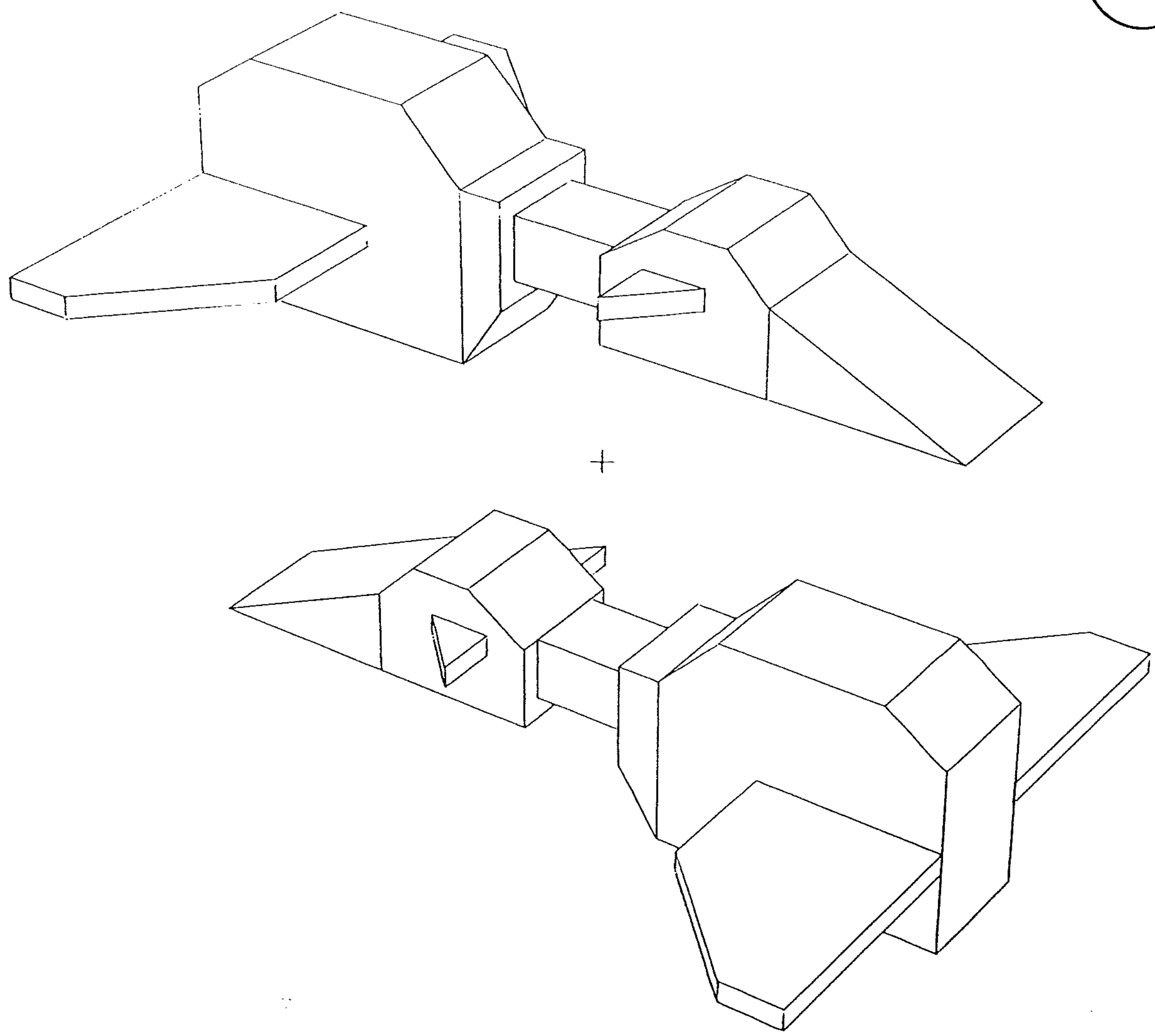
12

Your name and tutor group	Project title	Date
....	....	....

Dimensions of each cuboid				Position of each cuboid		
				coordinates of corner *		
Part	Width X	Height Y	Depth Z	Xcoord	Ycoord	Zcoord

Notes: * Position of each cuboid - record the coordinates of the lower left back corner.

Computer aided design cuboid data



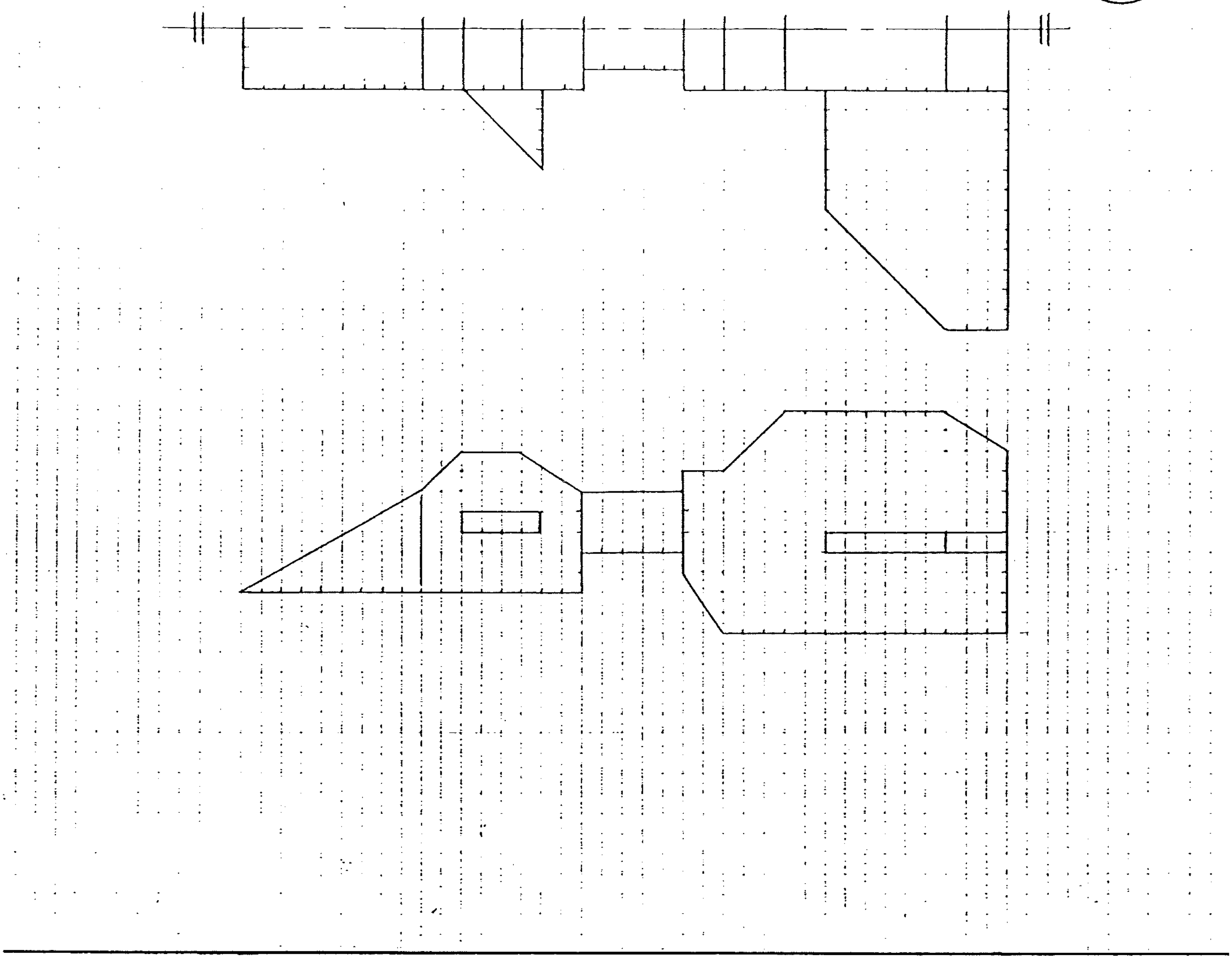
Two computer generated pictorial views of Spacecraft 2

Instructions for Spacecraft 2

1. Modify the spacecraft design by adding parts, and by altering the shape of wings and body. Use scrap isometric and squared paper to develop ideas.

2. Make an isometric view of your design. Use A3 size isometric paper. Colour your isometric view to suit your own ideas - but take care to use shading —the surfaces facing the X direction should be darkest.

3. Make as many orthographic views as you think are necessary to communicate your design. Note: that you may have to use A2 size squared paper. Lightly colour your orthographic views.



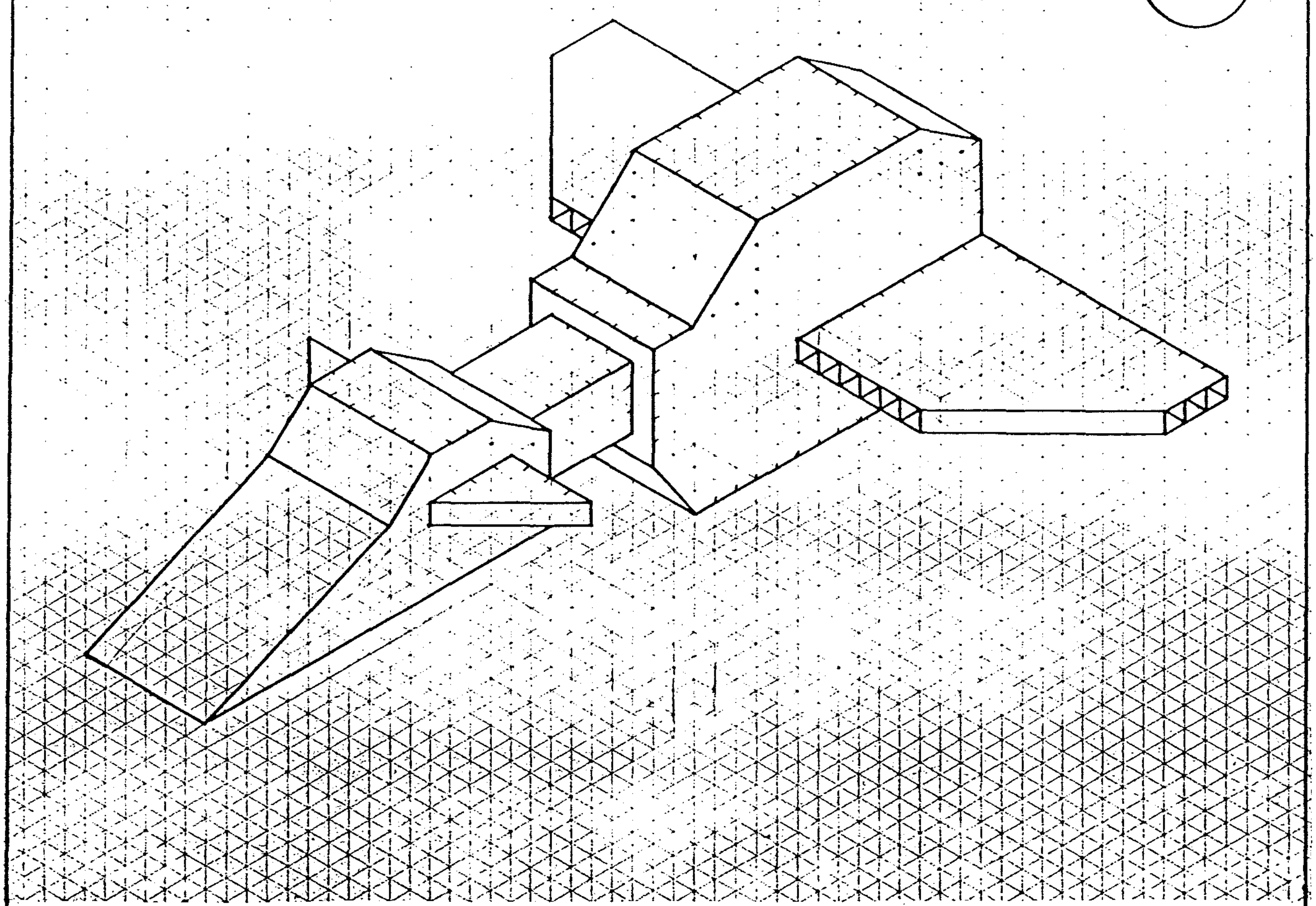
Essential information

The two orthographic views above provide exact information for drawing **Spacecraft 2.** Note that owing to shortage of space the top view is a partial view. The centre line with equals signs at each end is the **approved way** to draw partial views that are symmetrical.

Your redesigned version of Spacecraft 2 will probably require more than two views. Even using A2 size paper you may need to draw partial views or draw some views out of projection.

Spacecraft 2

15



Instructions

1. Modify   Modify the above design to suit your own ideas. Use some scrap isometric grid paper to explore your ideas. You will need A3 size isometric paper.

Note   Note that designs by other pupils are available to help you to improve your own ideas.

2. Colour   Colour your design to suit your ideas. Try to colour your spacecraft so as to make it look real.

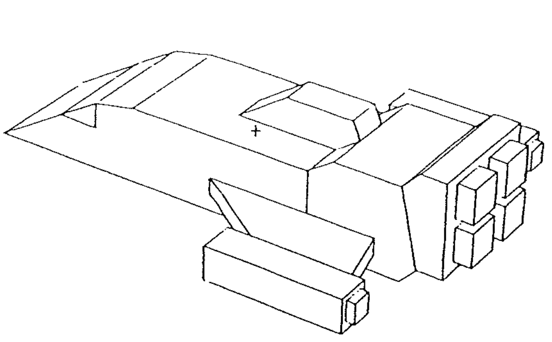
3. Make   Make two views in projection of your design. One view should be a top view and the other a side view. You will need A3 size squared paper.

4. Colour   Colour your orthographic views to match your isometric view.

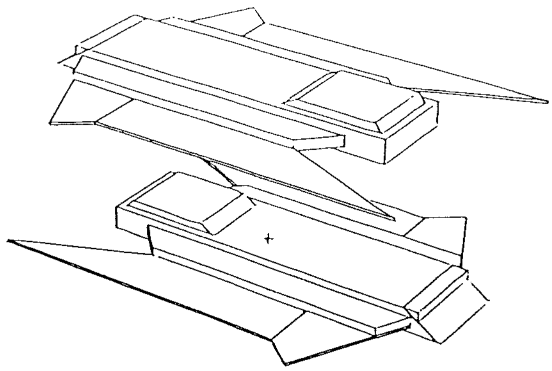
Spacecraft 2

Designed by Noah Rose pupil at Creighton School 1979

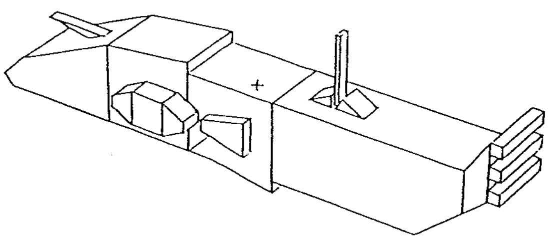
Scale: 1 square = 3 metres



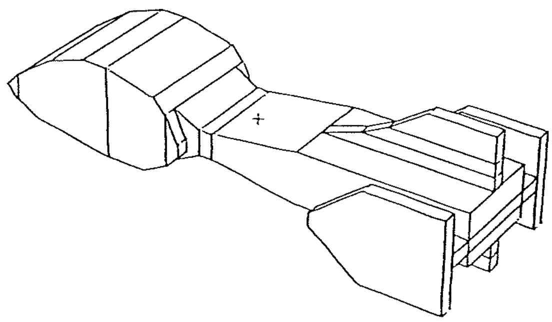
Rowan Burrough



Chris Hughes



Kim Osborne



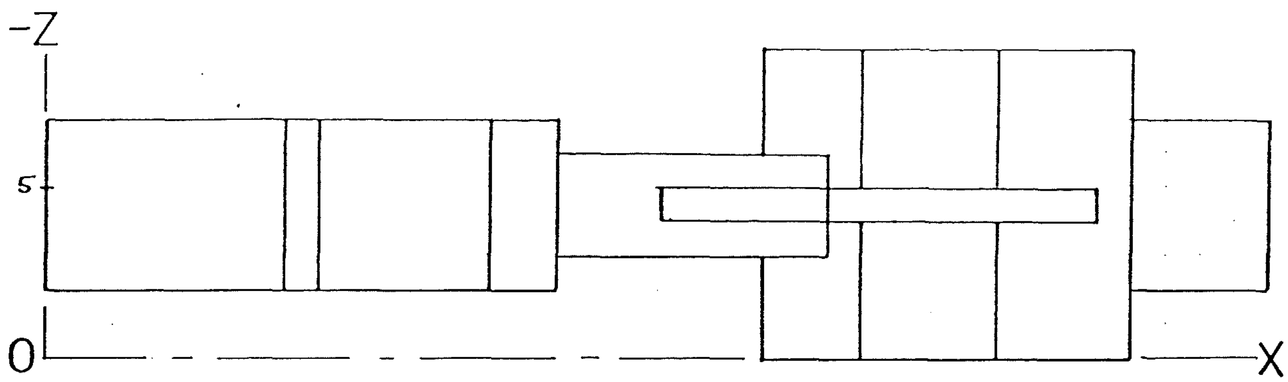
Naren Barfield

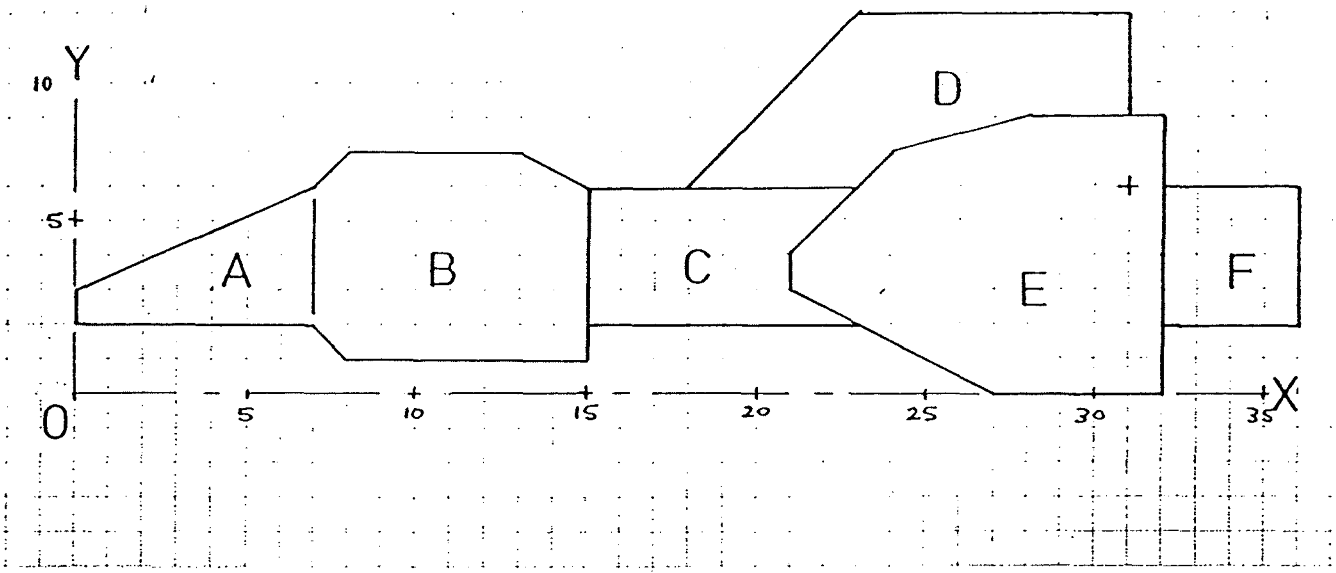
Spacecraft Project

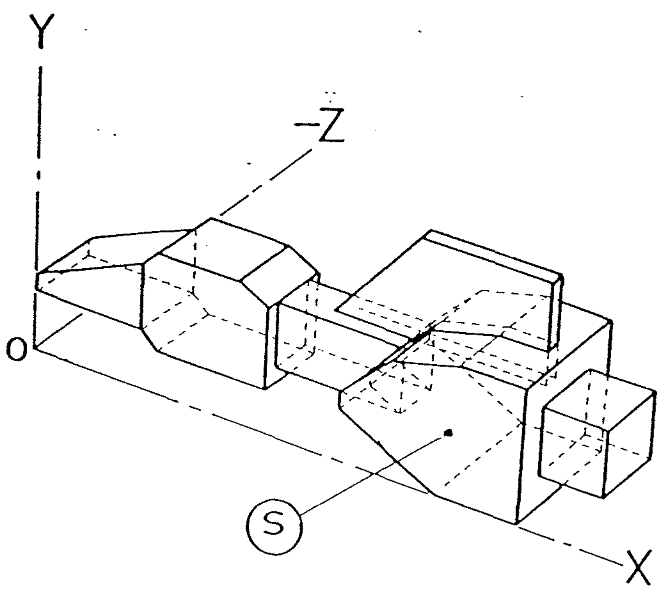
The drawings above produced by computer are views of spacecraft designed by school pupils. Each spacecraft can be analysed into parts that are prisms. Instructions for designing similar spacecraft are given on the next few pages.

Using Flowcharts

If you are not used to using a flowchart please make quite sure that you complete each instruction before continuing with the next. Instructions are placed in rectangular shapes, questions in diamond shapes. If in doubt ask!







Notes

1. There are 11 rectangular surfaces in the top view (view Y)
2. The surface marked S in the 3D view touches the XY coordinate plane.
3. The corner of part D shown by a + simplifies the XY coordinates. The computer program allows for intersecting surfaces.
4. The underneath surface of part E touches the XZ coordinate plane.

Start

Design a body of a spacecraft within the rules given below. Use A4 size squared paper. Draw two views a side elevation (Z view) and a plan view (Y view).

Rule 1. Each surface must be flat.
Rule 2. Each surface in the plan view must be rectangular in shape.
Rule 3. All edges of your design must be made by joining point to point.

Add XY coordinate axes to your side elevation make the axes touch your view. Scale both axes from the origin every 5 squares 0,5,10,15.....

Add XZ axes to your plan view make the axes touch the nearest vertical surface. Note the Z axis is going in the -Z direction. Scale the Z axis as before.

Study the example opposite carefully.

Divide your side elevation into parts according to the rules given below.

Rule 4. A side elevation consisting of more than 7 lines (8 points) must be divided into parts.
Rule 5. Each part of your elevation must be convex.

Label each part of your side elevation A,B,C,...

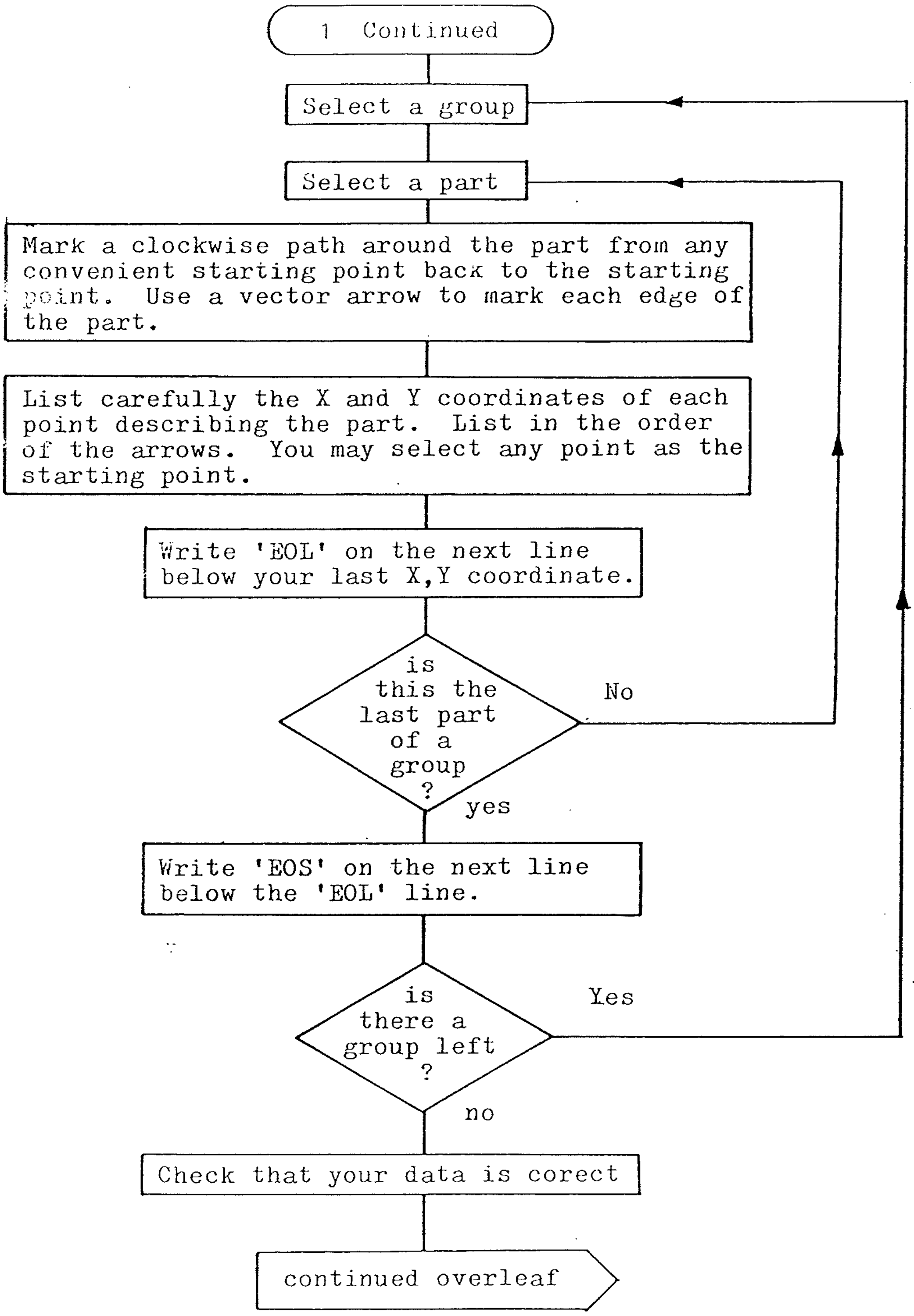
Check your work. Ask your teacher to check your work before proceeding to the next step.

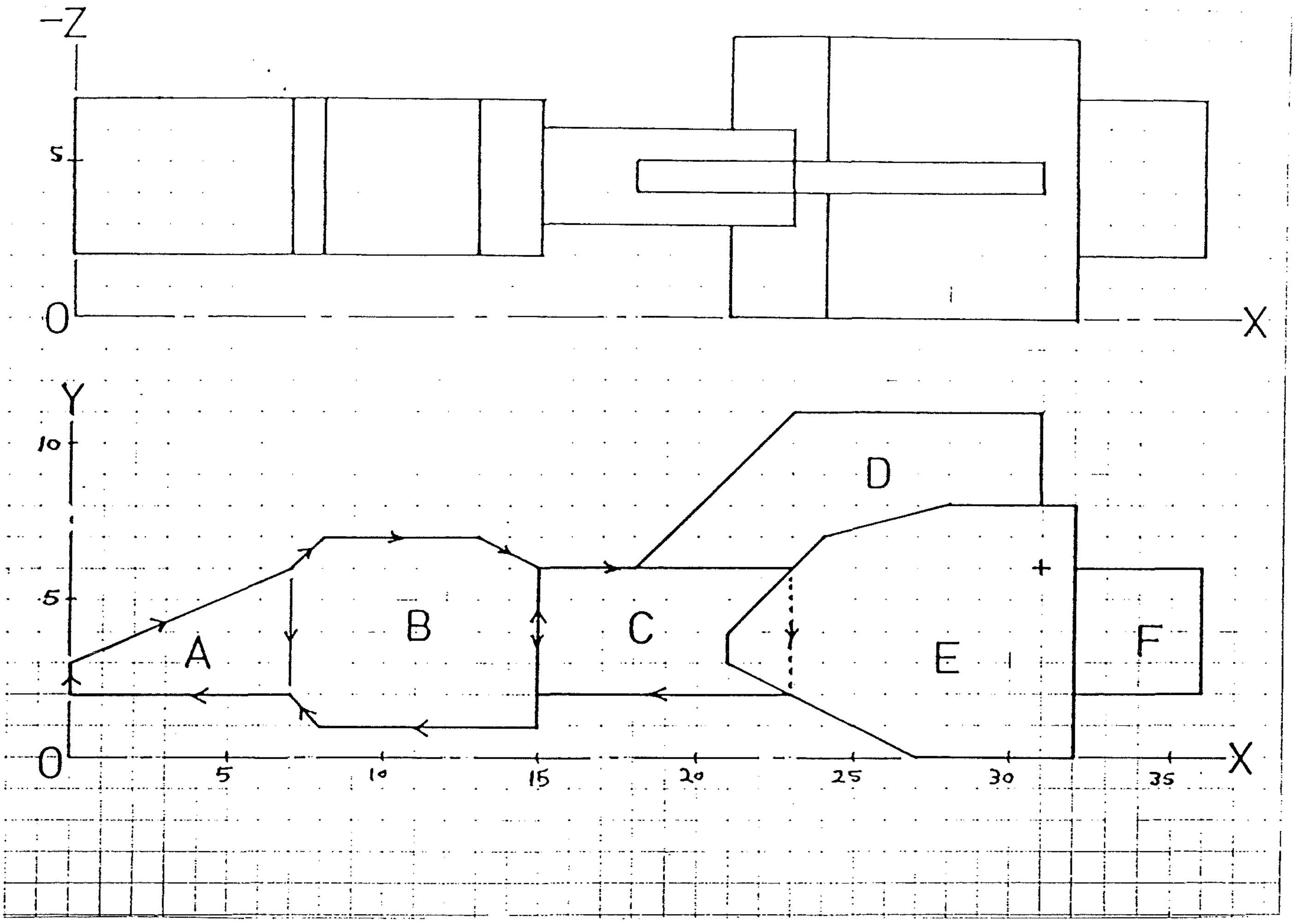
Group together the parts of your side elevation according to the rule given below.

Rule 6. Parts that have the same thickness must be grouped together. The parts must also be the same distance from the XY coordinate plane.

Identify each group by colouring the parts in the same group the same colour.

Continued overleaf


1 Continued
Select a group
Select a part
Mark a clockwise path around the part from any convenient starting point back to the starting point. Use a vector arrow to mark each edge of the part.
List carefully the X and Y coordinates of each point describing the part. List in the order of the arrows. You may select any point as the starting point.
Write 'EOL' on the next line below your last X,Y coordinate.
is this the last part of a group ?
No
yes
Write 'EOS' on the next line below the 'EOL' line.
is there a group left ?
Yes
no
Check that your data is corect
continued overleaf



Part A

0,2
0,3
7,6
7,2
0,2
EOL

Part B

7,6
8,7
13,7
15,6
15,1
8,1
7,6
EOL

Part F

32,6
36,6
36,2
32,2
36,6
EOL

EOS

Group 1. Thickness 5 Zmove=2

Part C

15,2
15,6
23,6
23,2
15,2
EOL
EOS

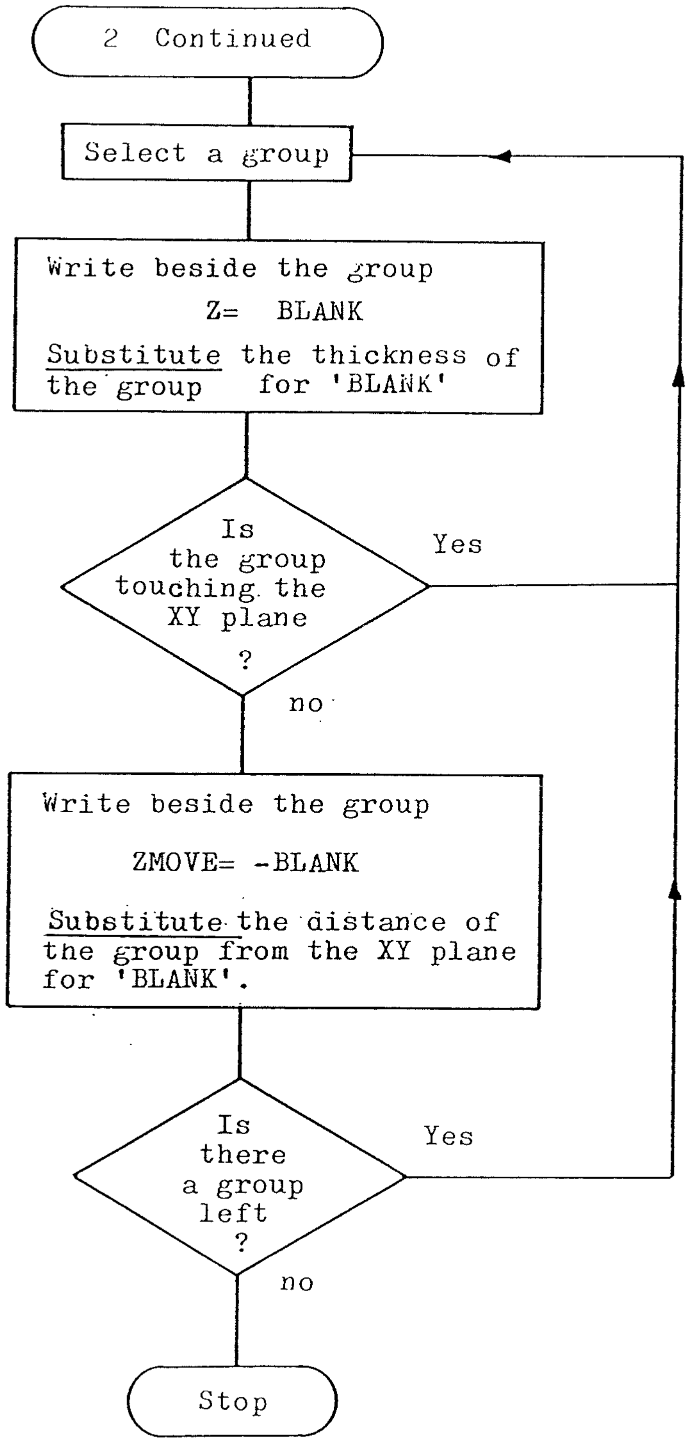
Group 2. Thickness 3 Zmove=3

Notes

The listing on the left shows <u>some</u> of the data for the above spacecraft. Note how the XY coordinates have been listed down the page, a comma separates the X from the Y coordinate. The listing has been designed for ease of entry at a computer terminal

EOL marks the end of a contour.
EOS marks the end of a component part.

The computer program will generate the necessary Z coordinates and surfaces.


2 Continued
Select a group
Write beside the group
Z= BLANK
Substitute the thickness of the group for 'BLANK'
Is the group touching the XY plane ?
Yes
no
Write beside the group
ZMOVE= -BLANK
Substitute the distance of the group from the XY plane for 'BLANK'.
Is there a group left ?
Yes
no
Stop

Start

Design the wings for your spacecraft body within the rules given below. Use squared paper, A3 size if necessary. Copy your view of the body allow plenty of room for the wings.

Rule 1 Each surface must be flat.

Rule 2 Each surface in the side elevation must be rectangular in shape.

Rule 3 All edges of your design must be made by joining point to point.

Study the example opposite carefully.

Add XZ axes to your plan view in exactly the same positions relative to the axes for the body. If necessary make the axes longer. Scale the axes as before include the minus sign where necessary.

Divide your plan view into parts according to the rules below.

Rule 4 A plan view of a wing part consisting of more than 7 lines (8 points) must be divided into parts.

Rule 5 Each part of your plan view must be convex.

Note Your wings may go right through the body. The computer program will work out where the wing penetrates the body.

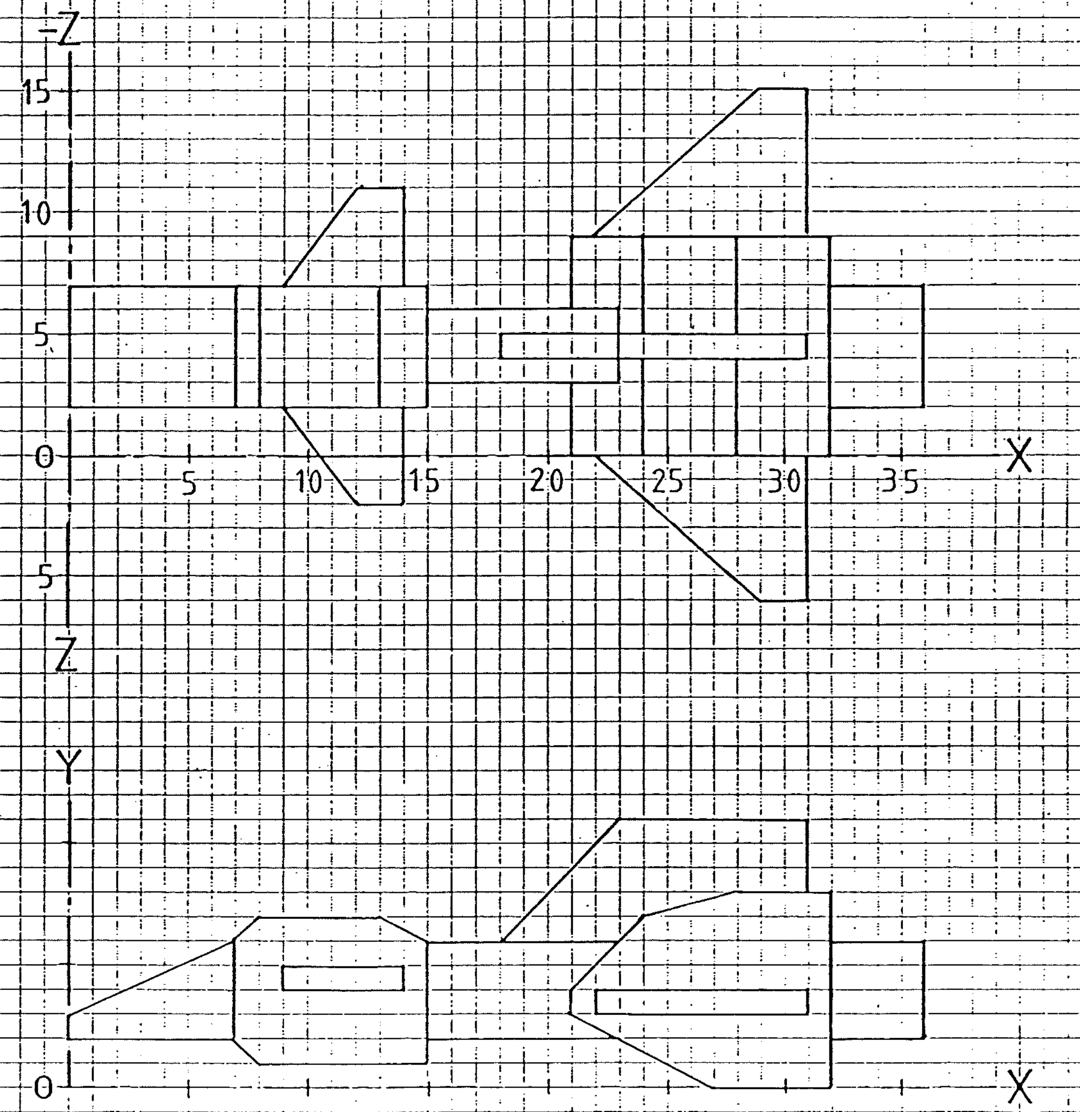
Label each part of your plan view A,B,C,.....

Check your work and ask your teacher to check your work before carrying on to the next step.

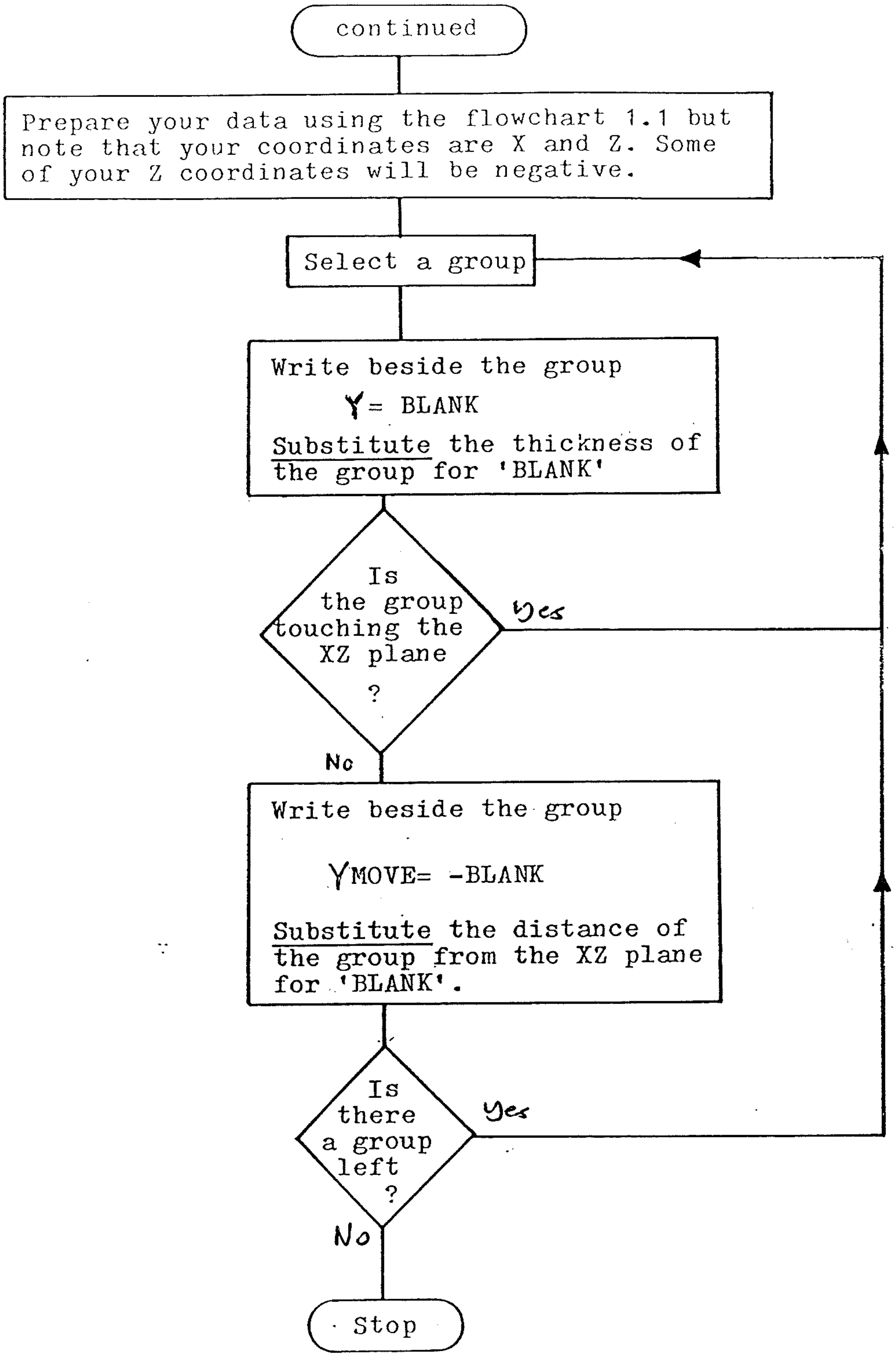
Group together the parts of your plan view according to the rule given below.

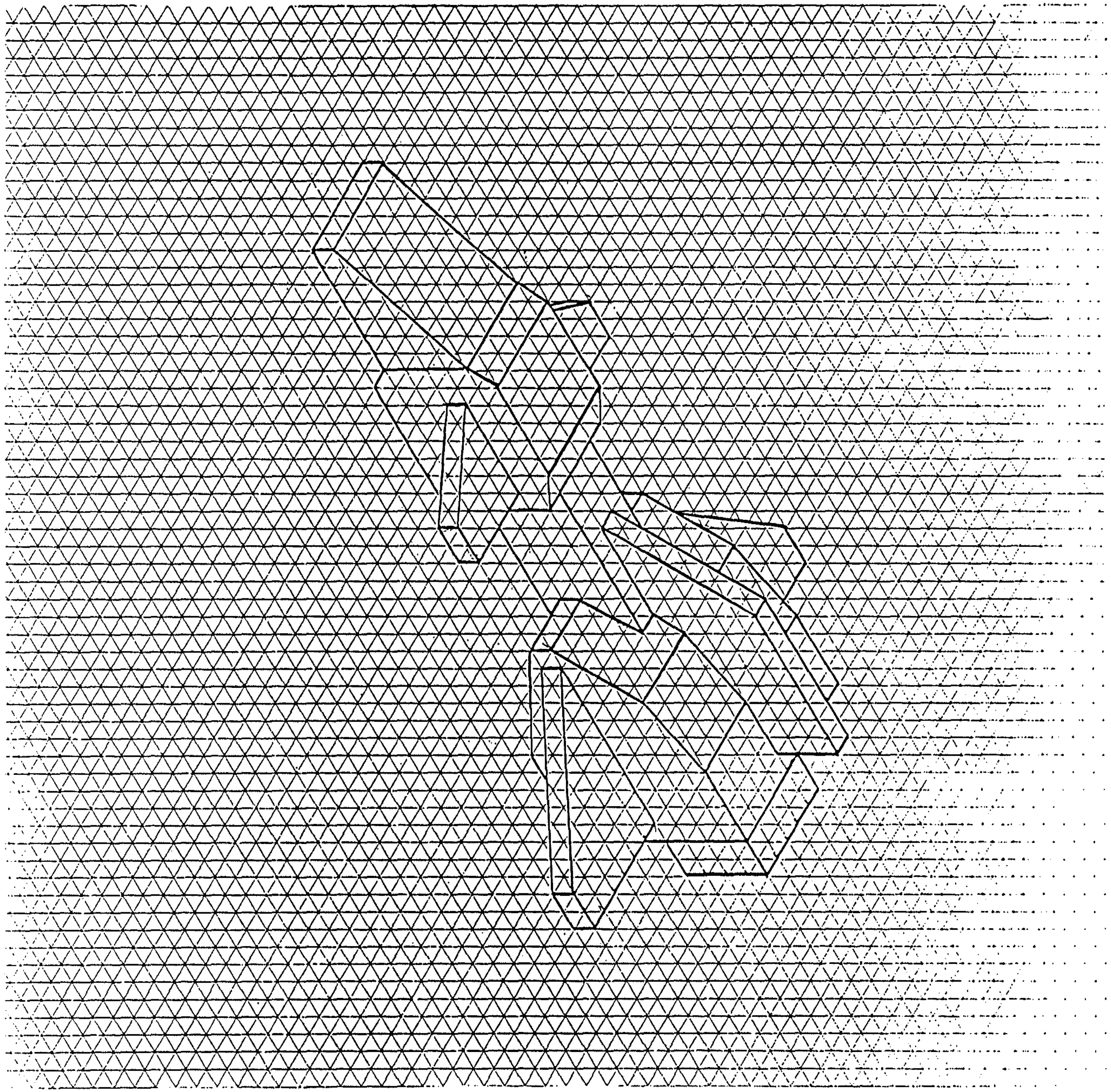
Rule 6 Parts that have the same thickness must be grouped together. The parts must also be the same distance from the XZ coordinate plane.

continued overleaf



-Z
15
10
5
0
5
Z
5
10
15
20
25
30
35
X
Y
0
X


continued
Prepare your data using the flowchart 1.1 but note that your coordinates are X and Z. Some of your Z coordinates will be negative.
Select a group
Write beside the group
Y= BLANK
Substitute the thickness of the group for 'BLANK'
Is the group touching the XZ plane ?
Yes
No
Write beside the group
YMOVE= -BLANK
Substitute the distance of the group from the XZ plane for 'BLANK'.
Is there a group left ?
Yes
No
Stop



Computer Graphics Project

Design an object within the rules given below:

Rule 1 The object must be either a right prism or made from right prisms.

Rule 2 The prism base face or faces must face either the X,Y,or Z directions.

Rule 3 Your complete design must be presented as two orthographic views drawn in projection on square grid paper. You may of course make preliminary pictorial sketches to get some ideas.

<u>Note</u> Don't forget to make a title box.

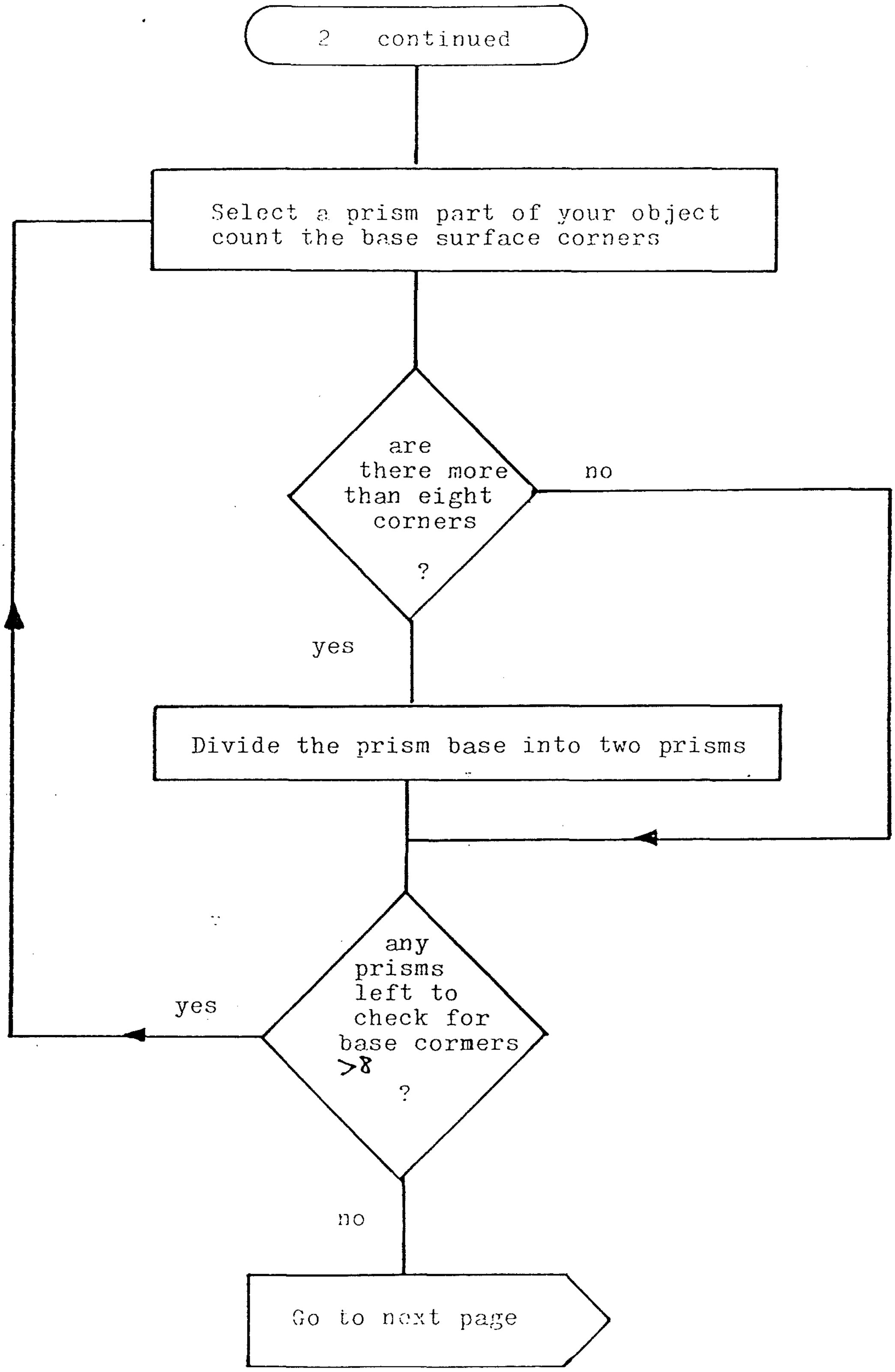
Add XYZ axes to your views.
Scale the axes: 0,5,10,15,..

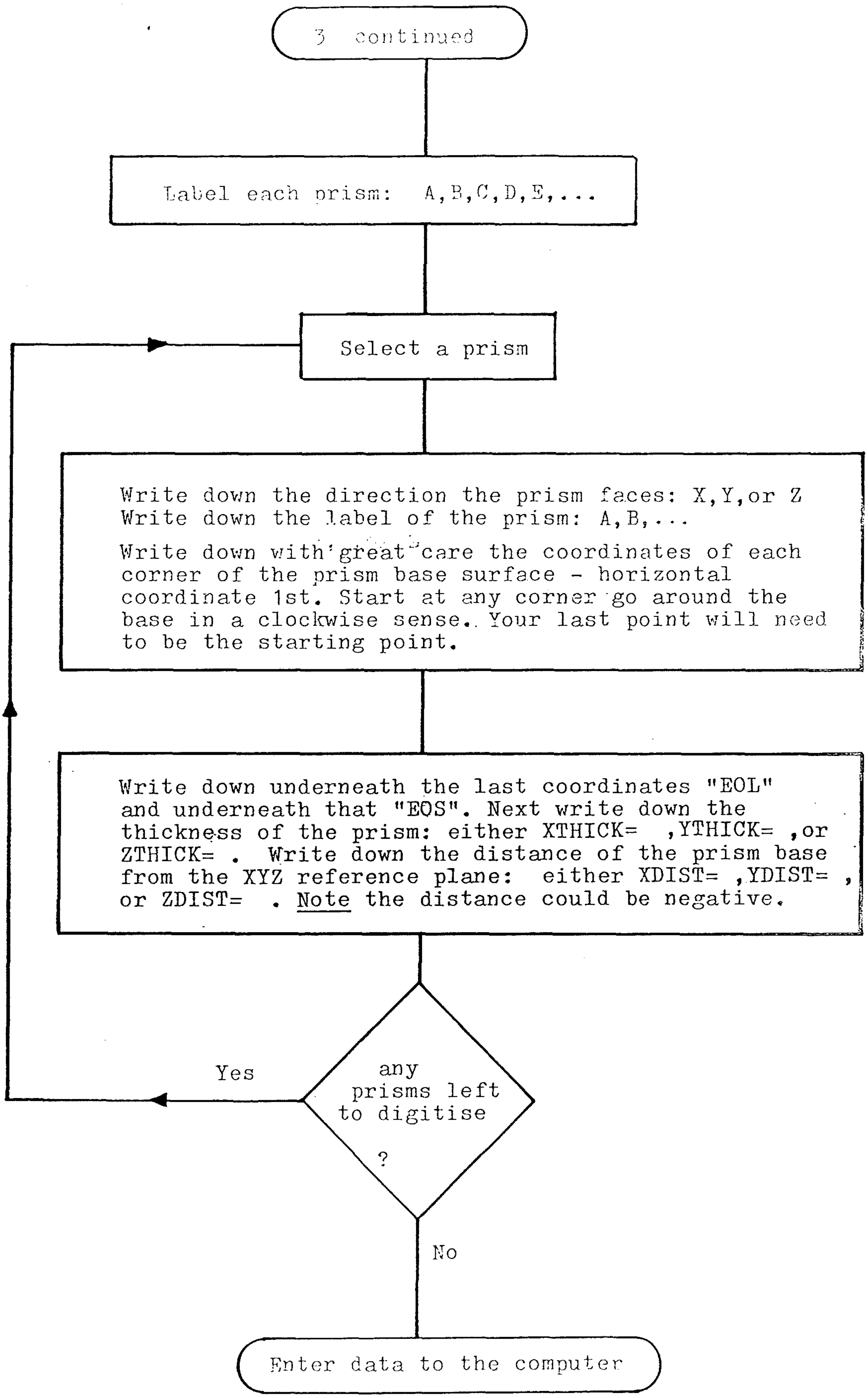
is your object a concave prism ?

No → Go to next page

Yes ↓

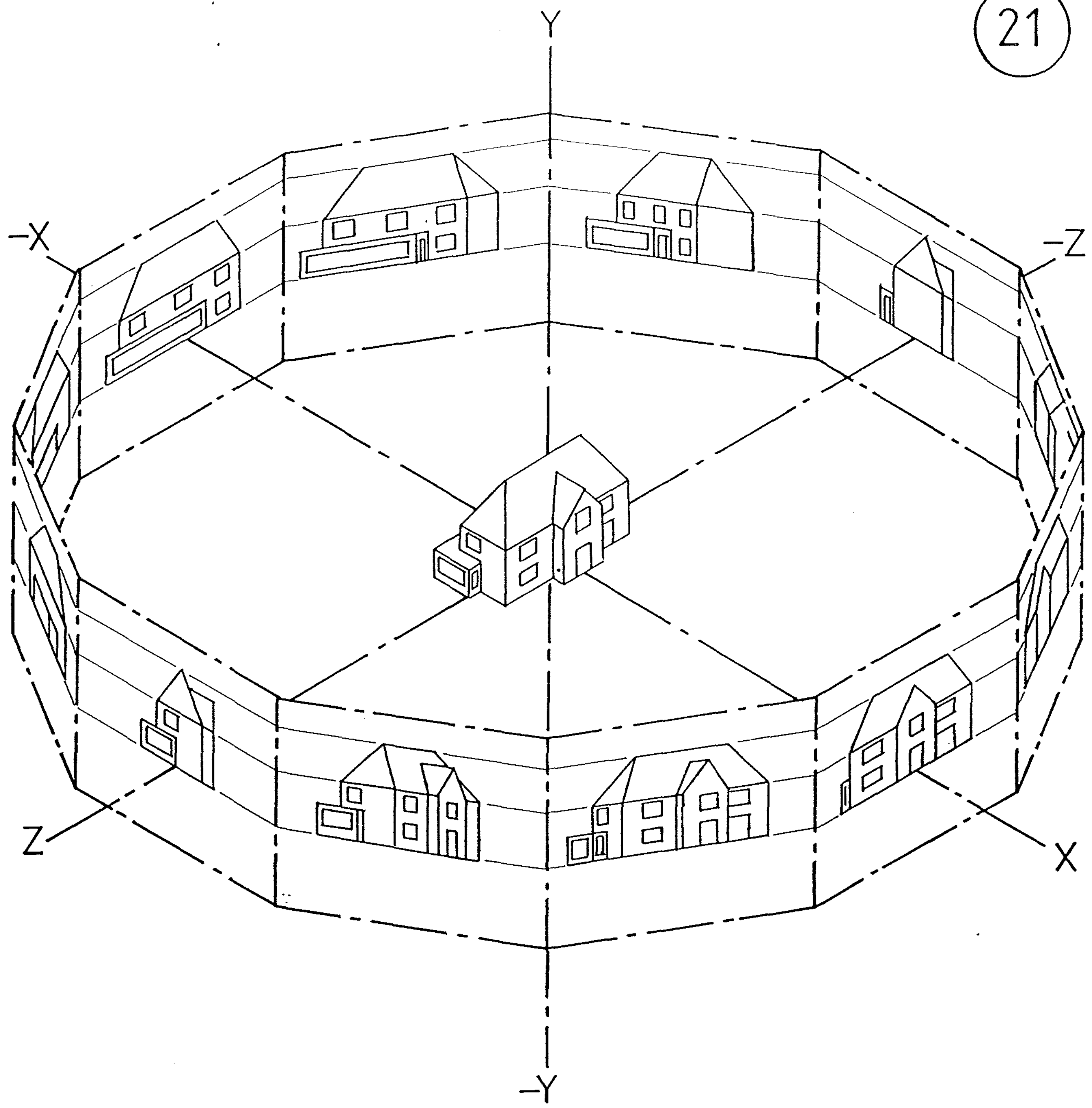
Divide your object so that it is made up of convex prisms


2 continued
Select a prism part of your object count the base surface corners
are there more than eight corners ?
no
yes
Divide the prism base into two prisms
any prisms left to check for base cormers >8 ?
yes
no
Go to next page


3 continued
Label each prism: A,B,C,D,E,...
Select a prism
Write down the direction the prism faces: X,Y,or Z
Write down the label of the prism: A,B,...
Write down with great care the coordinates of each corner of the prism base surface - horizontal coordinate 1st. Start at any corner go around the base in a clockwise sense. Your last point will need to be the starting point.
Write down underneath the last coordinates "EOL" and underneath that "EOS". Next write down the thickness of the prism: either XTHICK= ,YTHICK= ,or ZTHICK= . Write down the distance of the prism base from the XYZ reference plane: either XDIST= ,YDIST= , or ZDIST= . Note the distance could be negative.
any prisms left to digitise ?
Yes
No
Enter data to the computer

Your name and tutor group	Project title	Drg No
....	....	......

Computer aided design Prism data



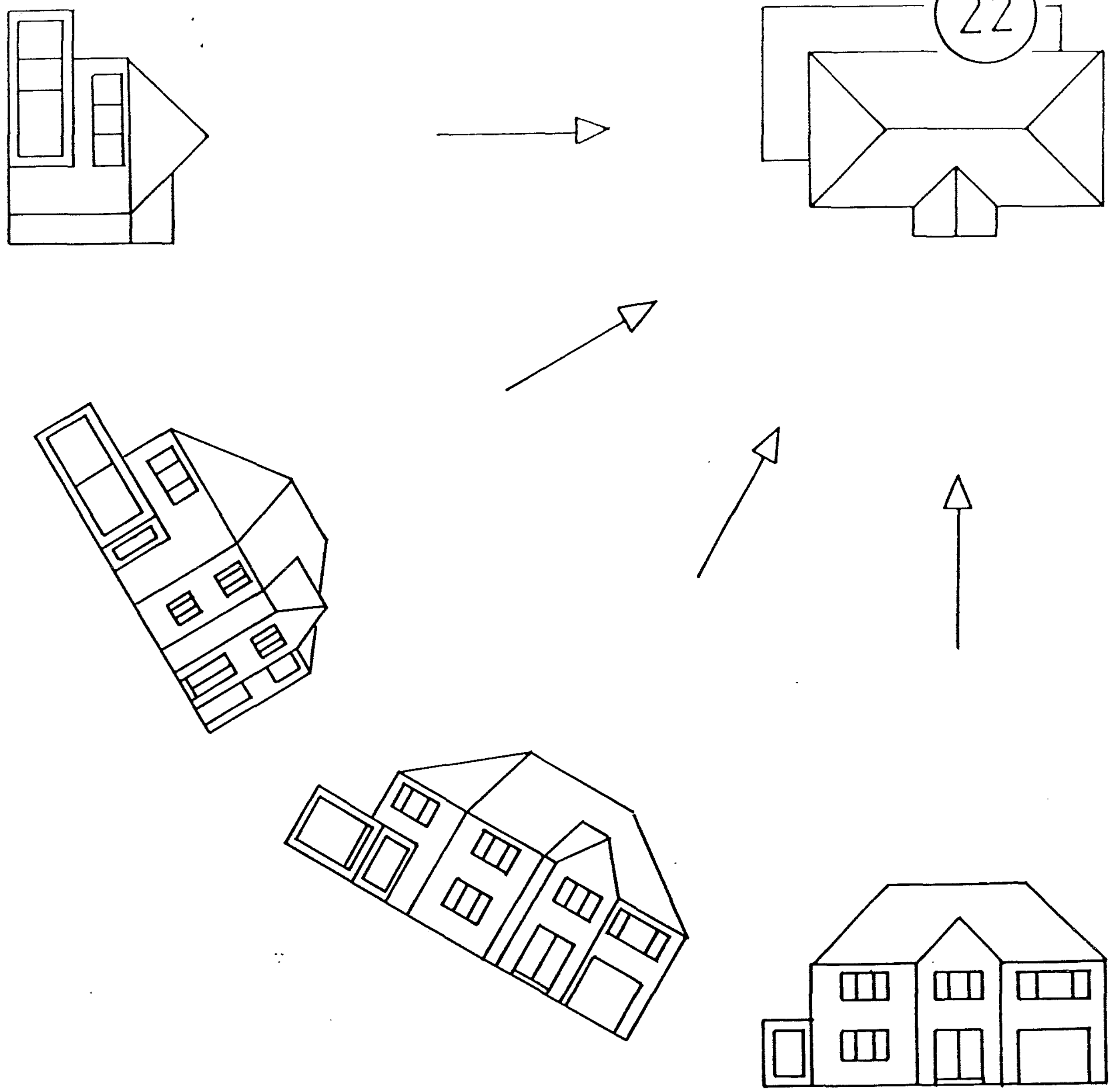
TECHNICAL WORDS

AUXILIARY ELEVATION — An auxiliary elevation is an extra view looking towards the sides of an object. The example above shows the 4 main views + 8 auxiliary views.

IMPORTANT NOTE

In an auxiliary elevation the height values are exactly the same as they are in the main views. The height values - measurements in the Y direction are the same because an auxiliary elevation is projected parallel to the XZ plane and is therefore not angled to the Y direction.

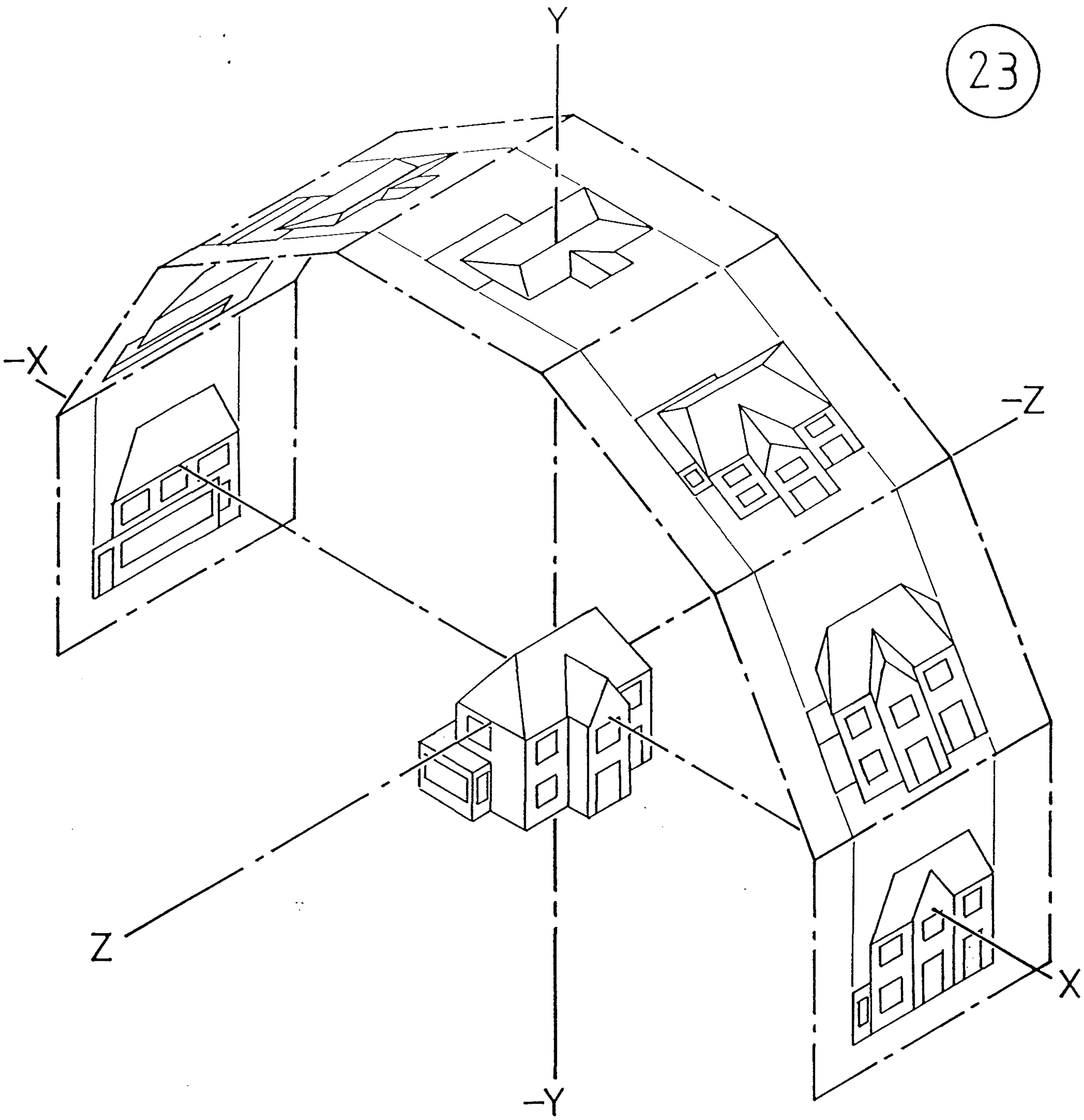
AUXILIARY ELEVATION IDEA



TECHNICAL NOTE

The drawing above shows 2 auxiliary views and 2 main views of the house. Each auxiliary view was made by projecting from the plan view and by projecting from the front view. Compasses were used to project from the front view. Exact directions for constructing an auxiliary elevation are given on the following two pages.

AUXILIARY ELEVATION



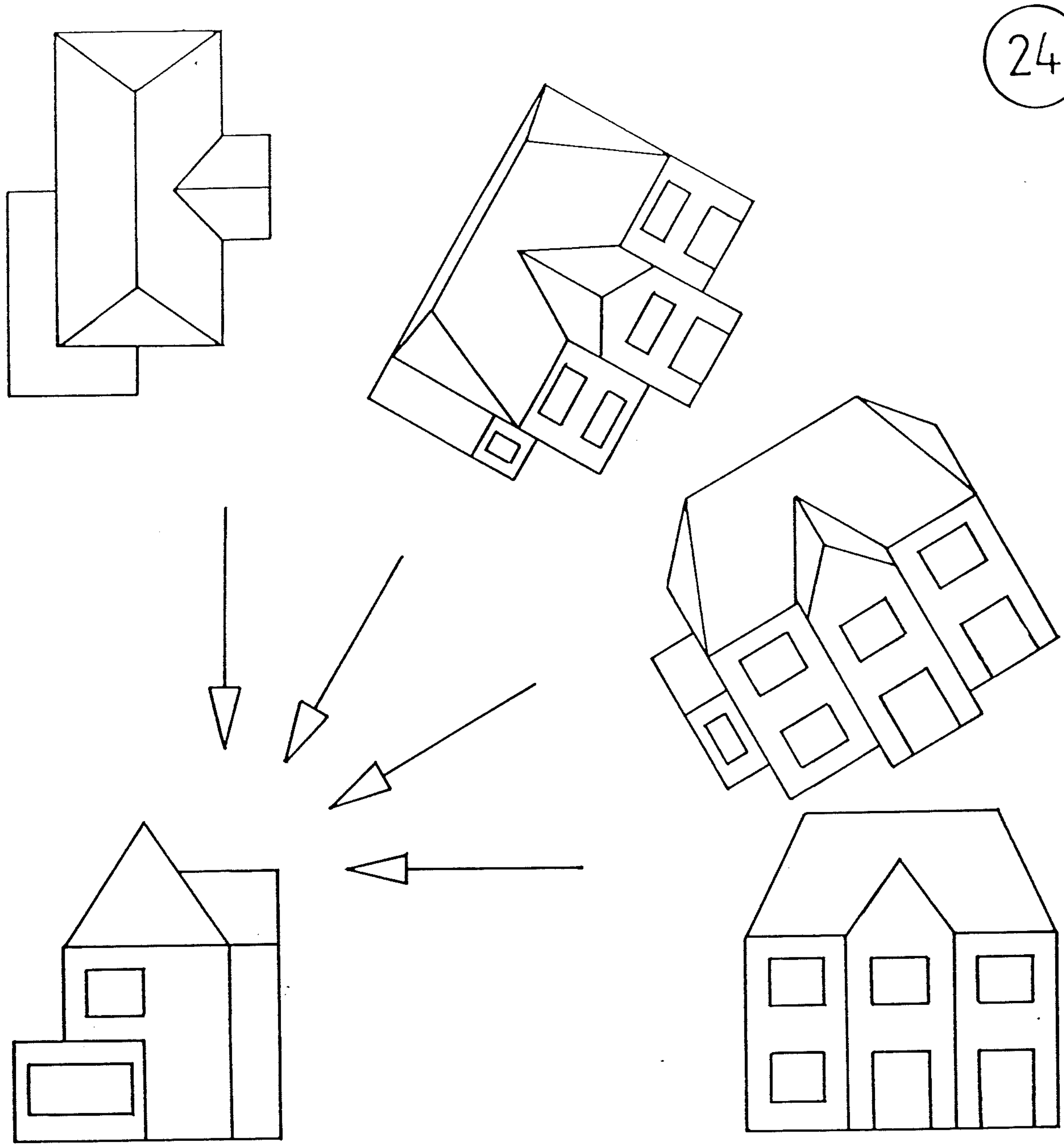
TECHNICAL WORDS

AUXILIARY PLAN — An auxiliary plan is an extra view looking down on an object.

IMPORTANT NOTE

In the example above the auxiliary views rotate around the Z axis. All measurements in the Z direction remain the same as the object. The Z measurements remain true length because the projectors are all parallel to the XY plane.

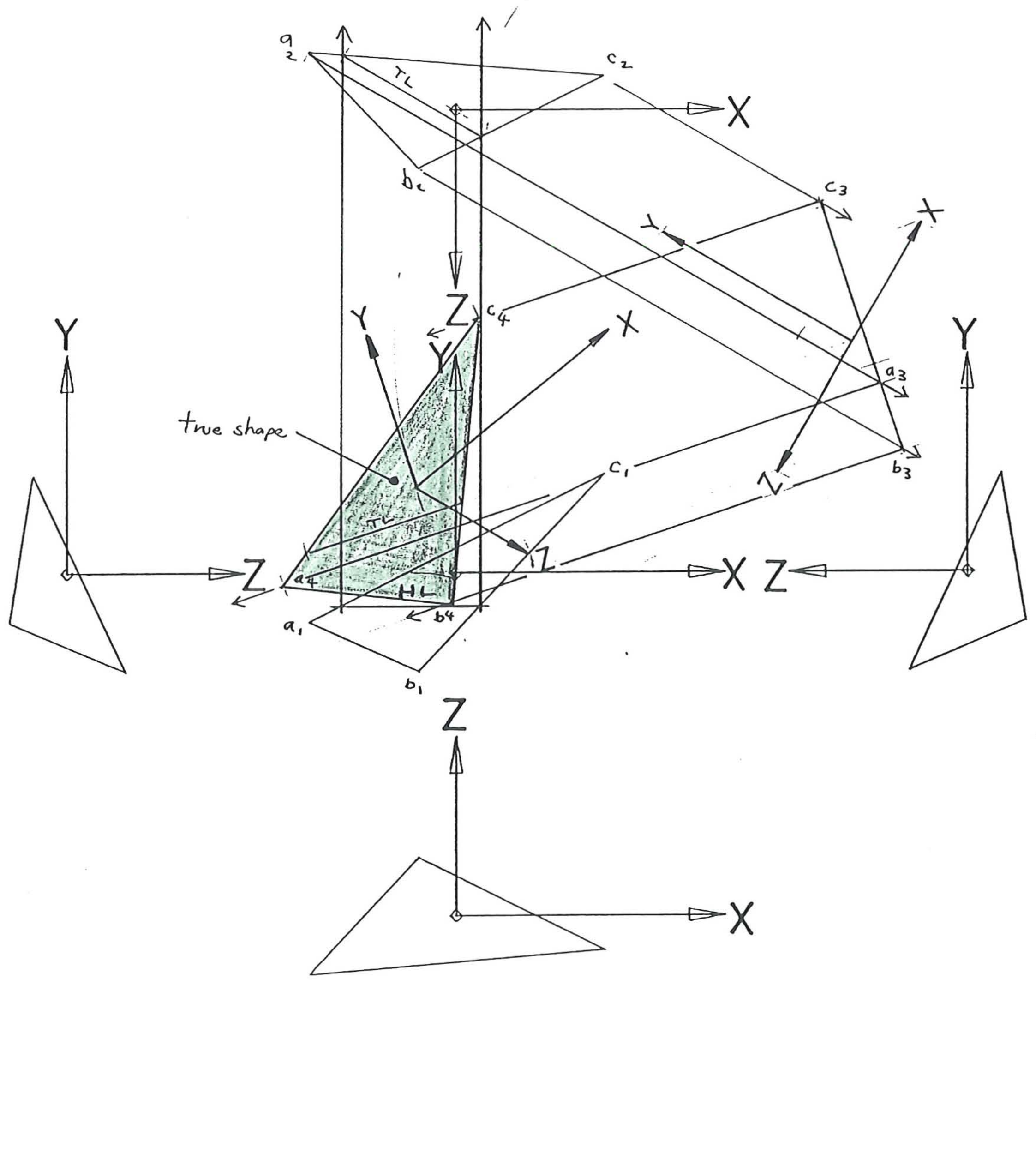
AUXILIARY PLAN IDEA



TECHNICAL NOTE

The drawing above shows 2 auxiliary plan views and 2 main views of a house. Each auxiliary view was made by projecting from both elevations. Compasses were used to project from the front view of the house. Exact directions for making an auxiliary plan view are given on the following two pages.

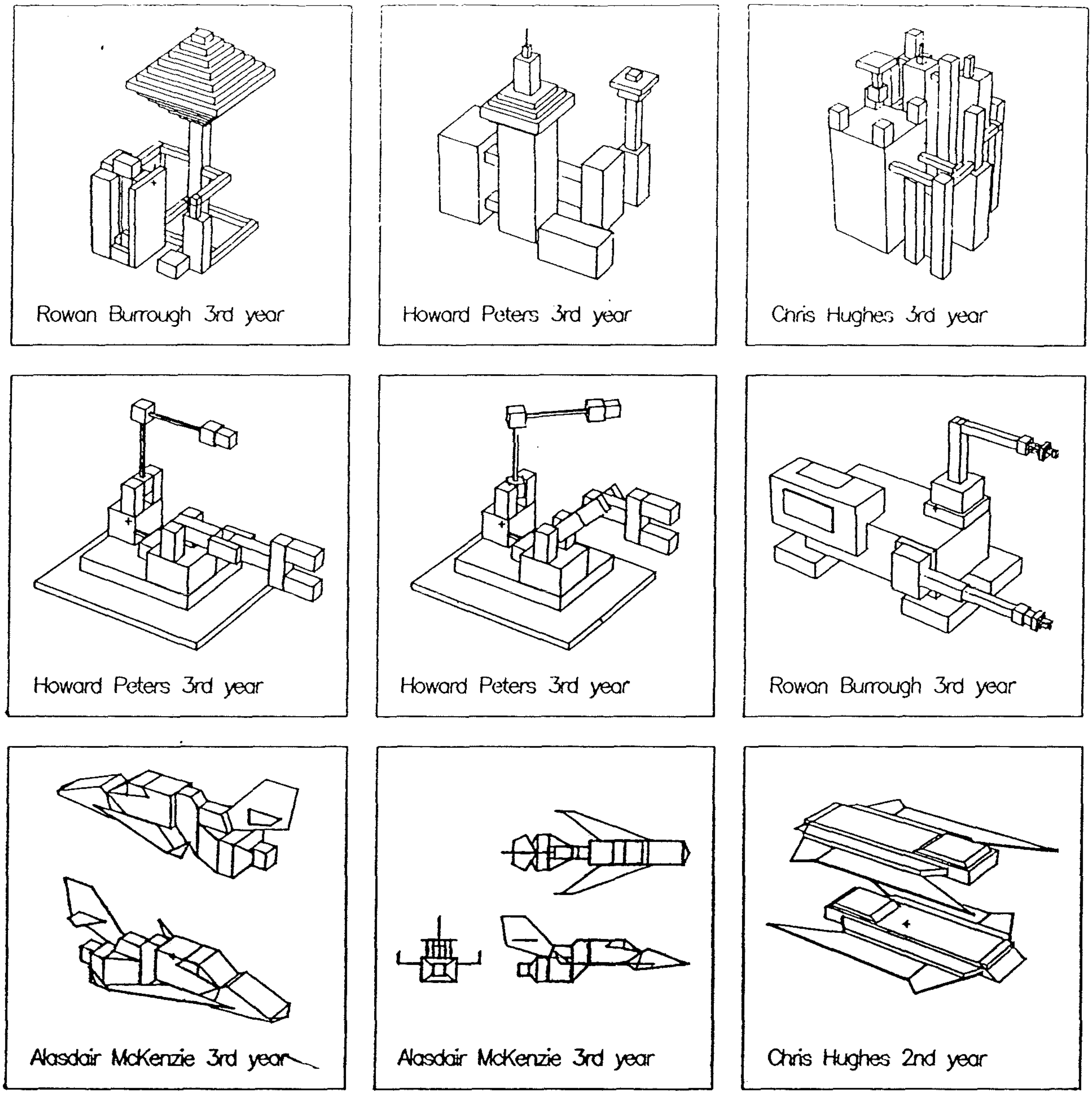
AUXILIARY PLAN



Set square experiment XYZ axes based

APPENDIX 3

PUPIL COMPUTER DRAWINGS AND SOURCE DATA

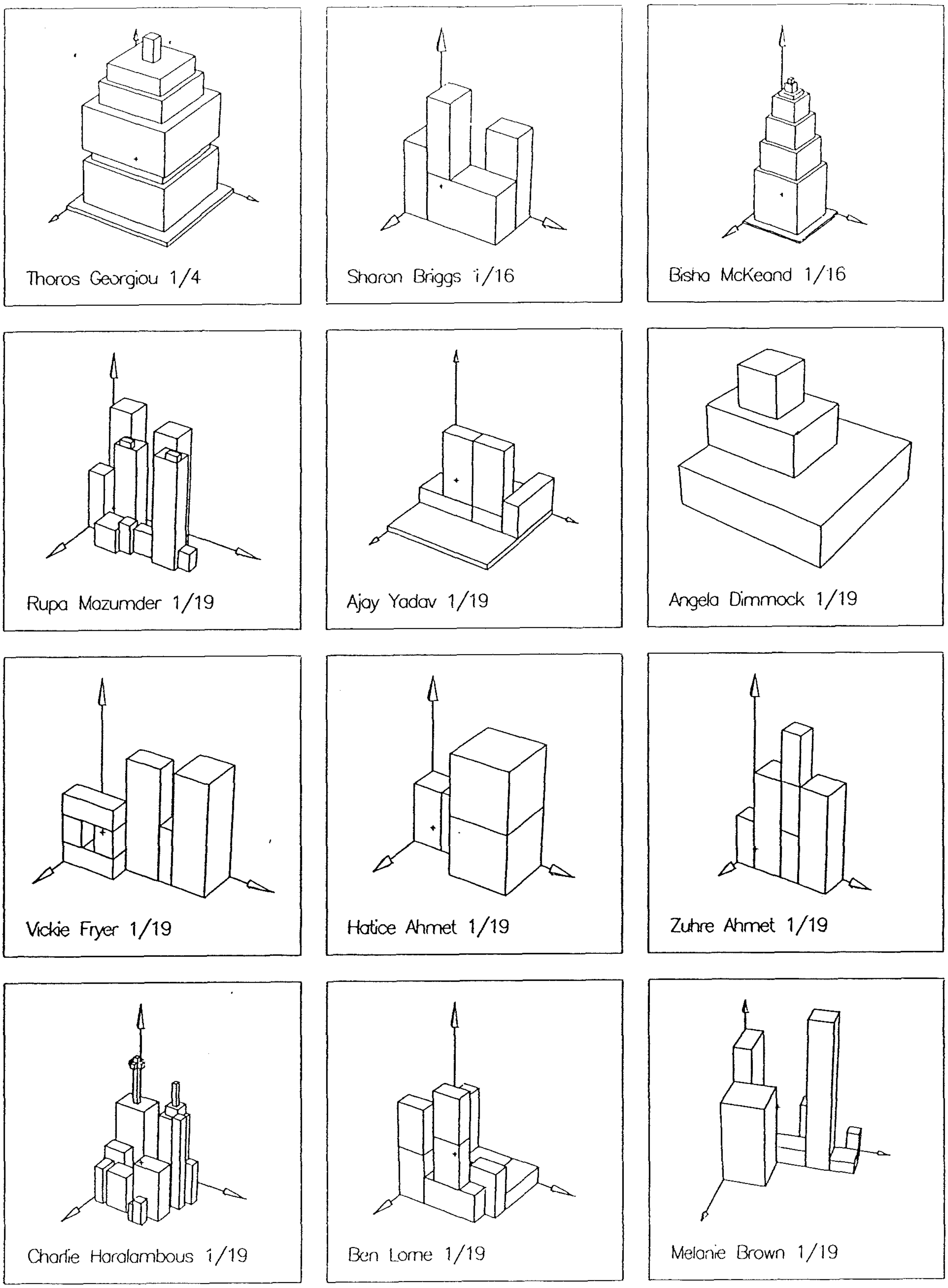


Fortismere Technical Graphics club

The drawings above are a selection of computer drawings from objects designed by pupils of Creighton school. Many of the above designs were produced in the Creighton Technical Graphics Club. Similar work is still possible not only for those pupils who I teach, but also for those pupils 1st to 7th year who can come to the Fortismere Technical Graphics Club. The club will also provide an opportunity for pupils to get help with examination work, homework, and to undertake work that cannot easily be done in lesson time. Mr. Edwards

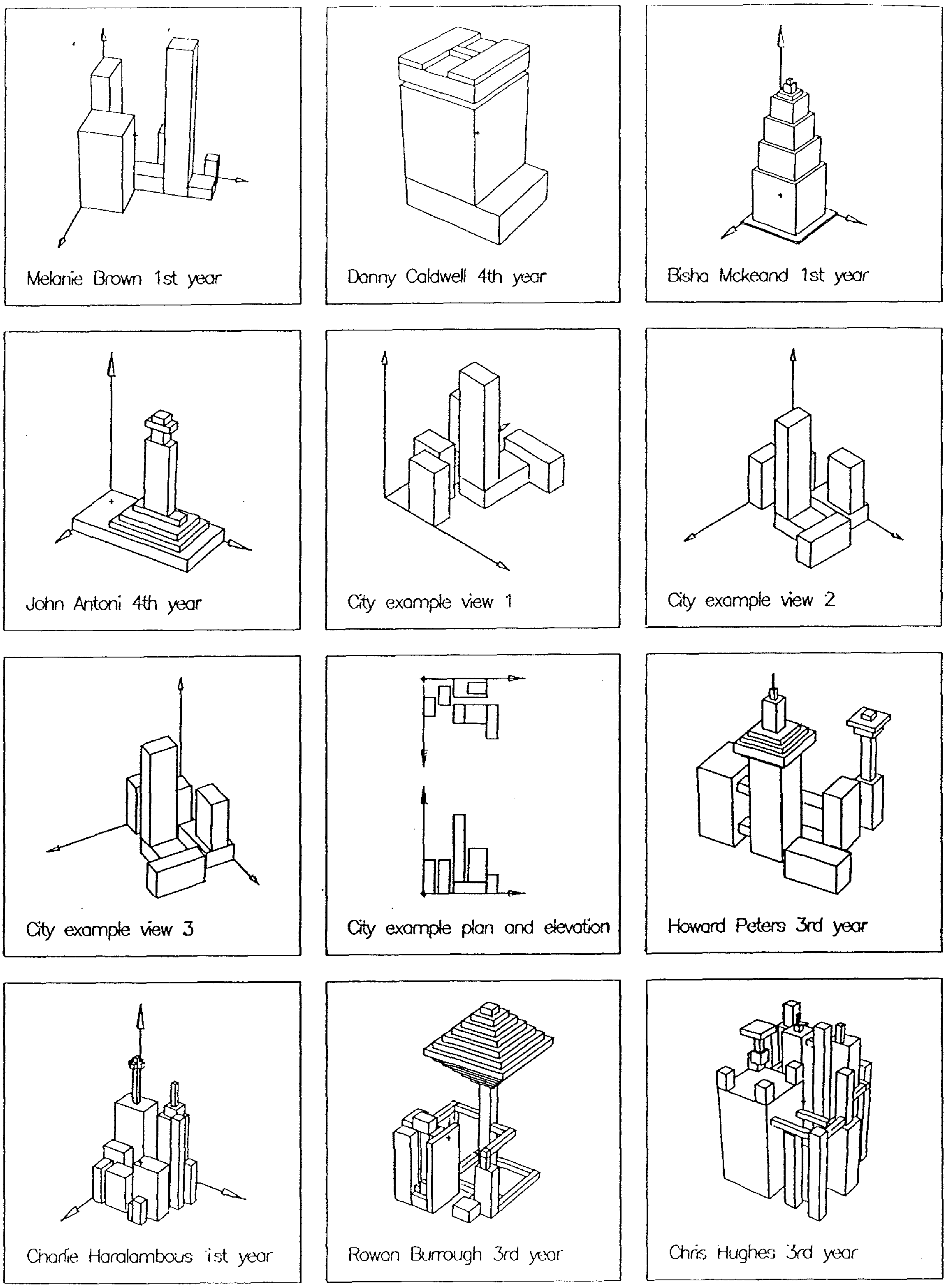
Place: North wing room 12
Time: every tuesday 3.50–5.00 (you can go home before 5.00 of course!)

Fig. 1. Poster, originally A2 size, for the Technical Graphics Club.



Computer produced views of City blocks designed by 1st years (1982–3)

Fig. 2. City Block Project a selection of designs by 1st years.



City blocks and buildings —computer generated views from data prepared by pupils of Creighton School (now Fortismere school) during the year 1982–3.

fig. 3. City Block Project a selection of designs by pupils of different ages.

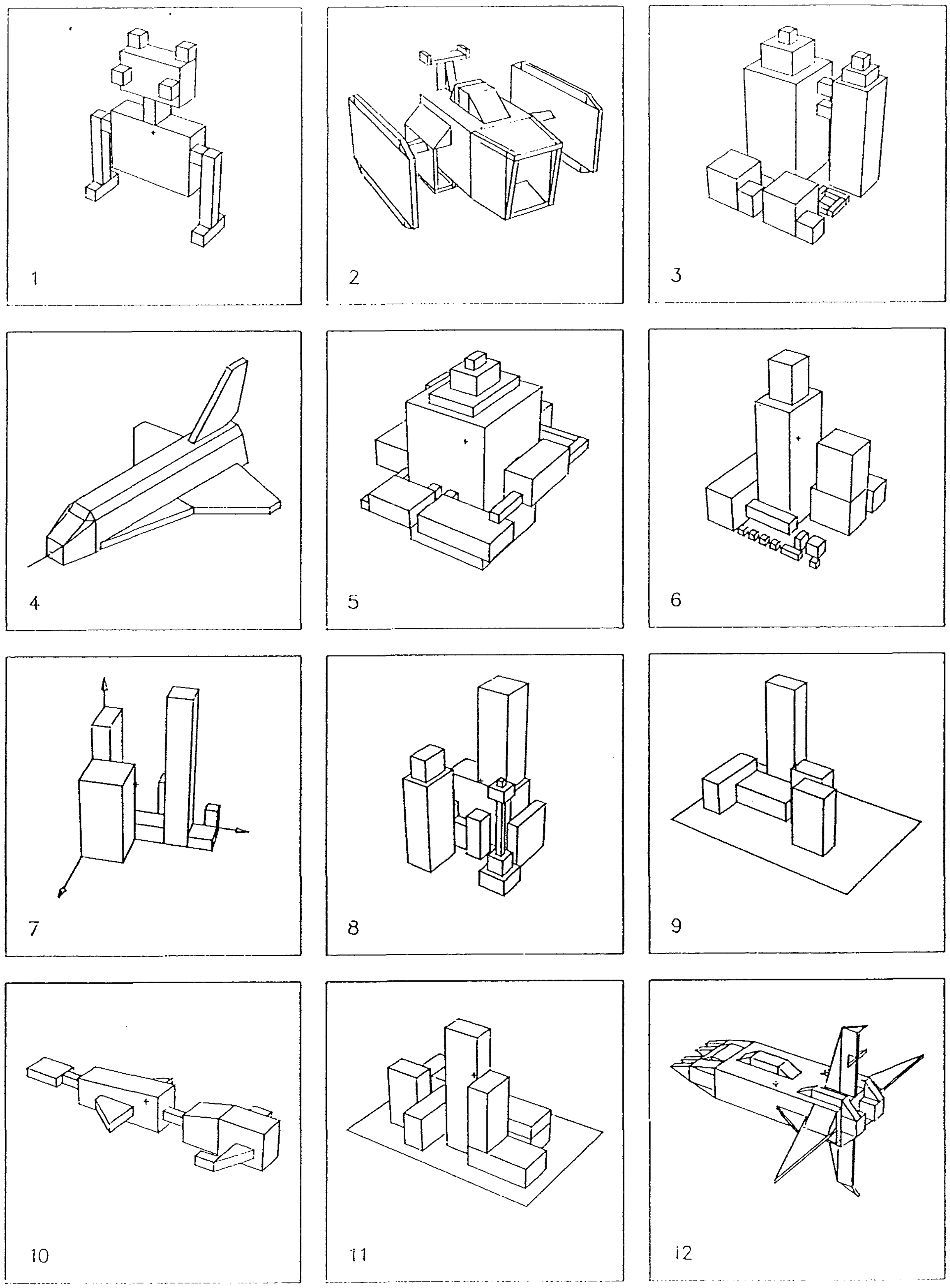


fig. 4. Miscellaneous computer drawings, mainly of pupils work, saved with the prefix PGE and plotted using the FRAMES program to produce 12 frames.

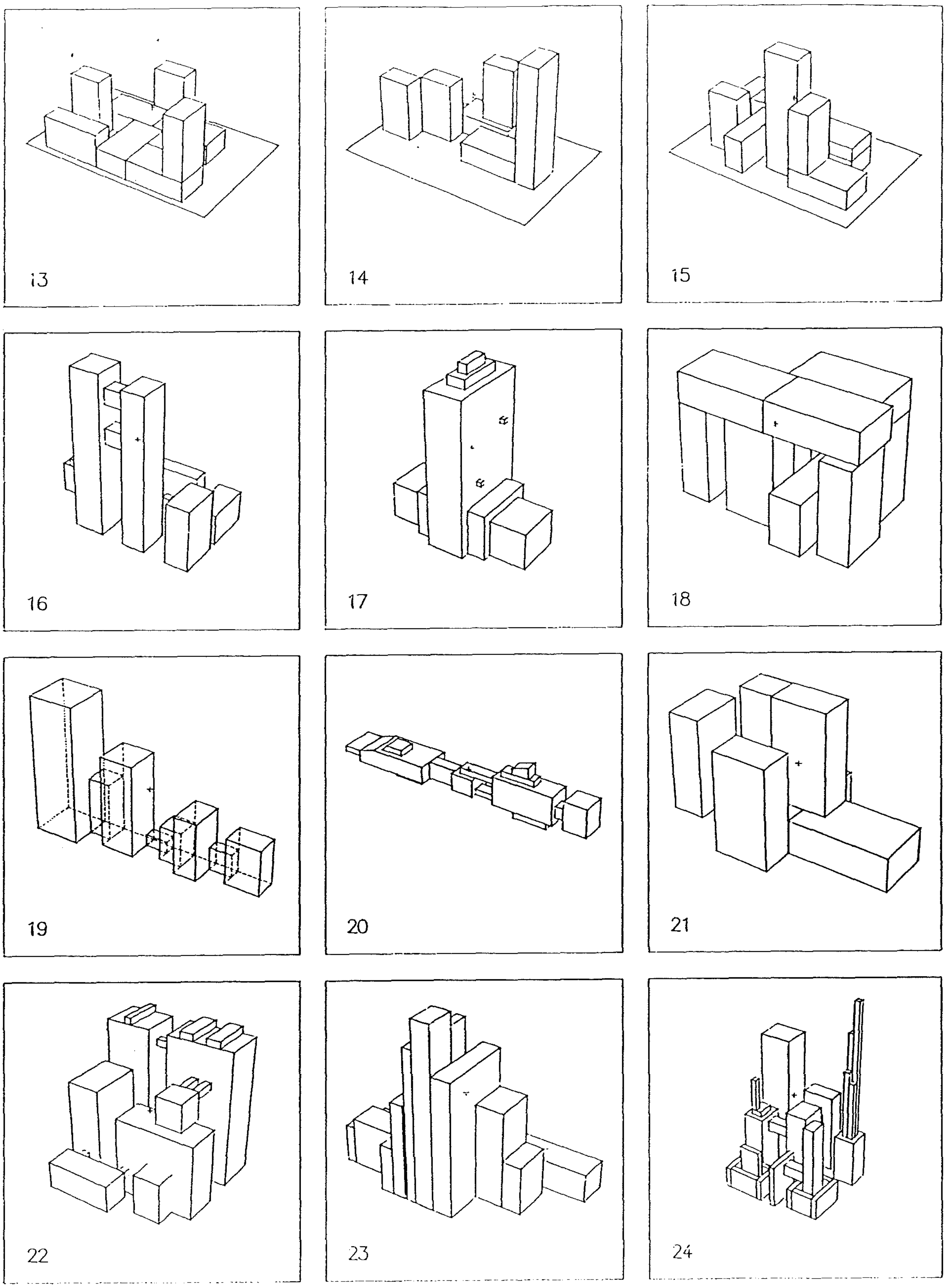


fig. 5. A further selection of saved plotfiles, including a drawing with hidden detail. Produced for reference purposes.

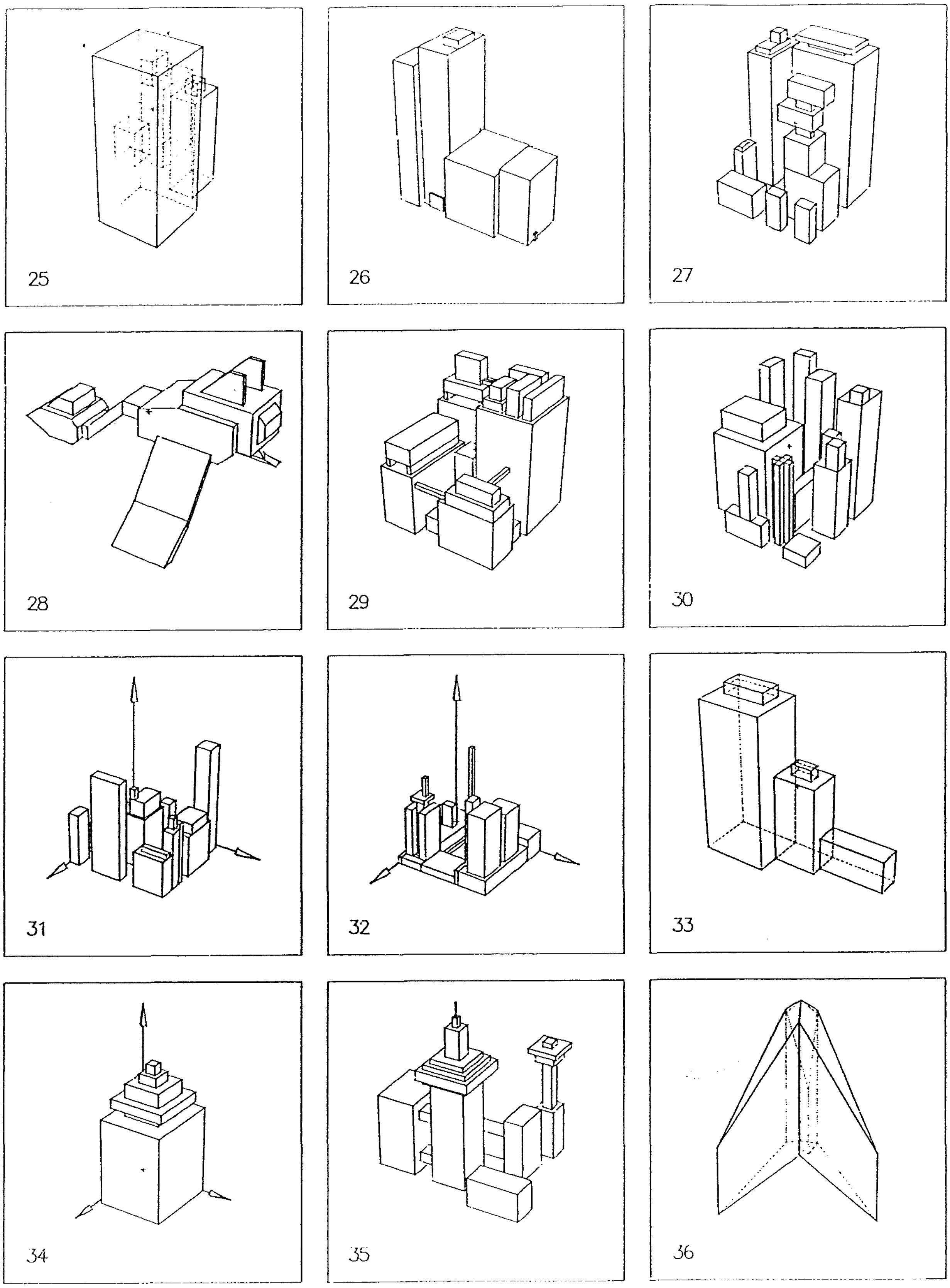


Fig. 6. Plotfiles 25-36. Frame 36 is a perspective view of the support for the fuel units of the Nuclear Rocket see Appendix 4

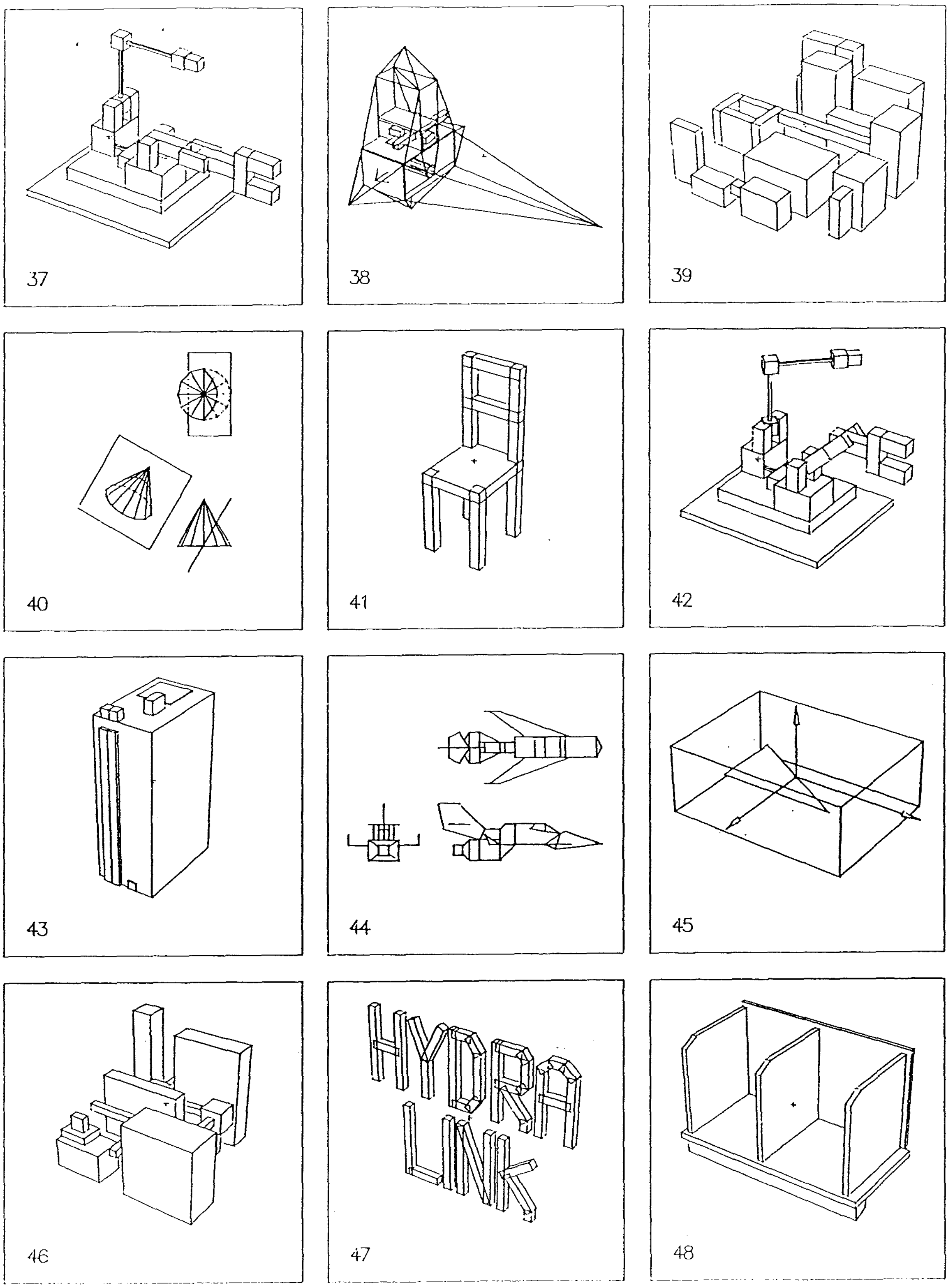


Fig. 7. Plotfiles 37–48. Frame 47 is a plot of the title for one of Clive Carter's 'A' level Design and Technology projects. Frame 48 is a plot of Martin Decker's Book Trough design, which was part of his CSE coursework for graphical communication.

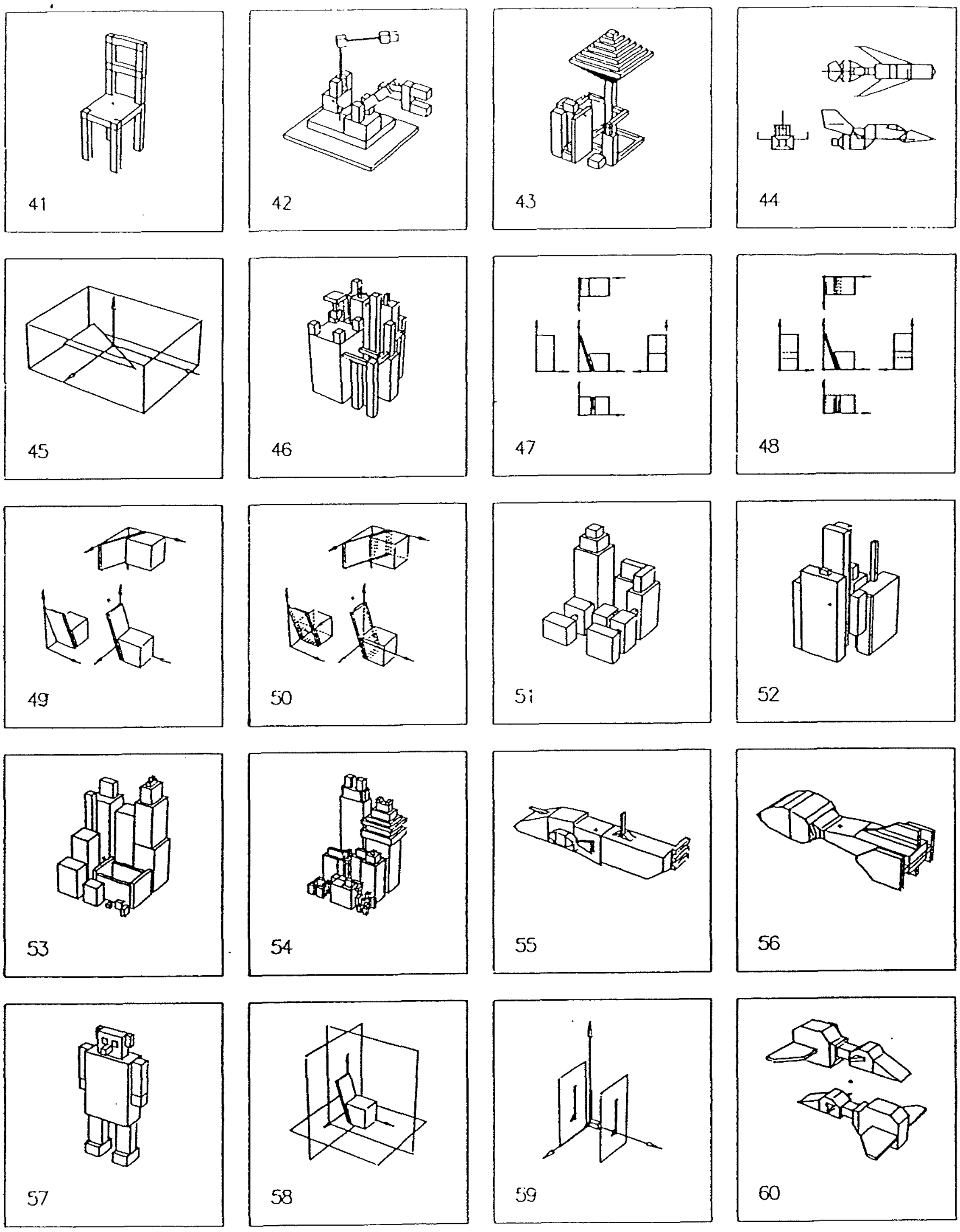


fig. 8. Plotfiles, output from the FRAMES program. Twenty frames, too small as plotted here (83 per cent of A4 size) except as reference material

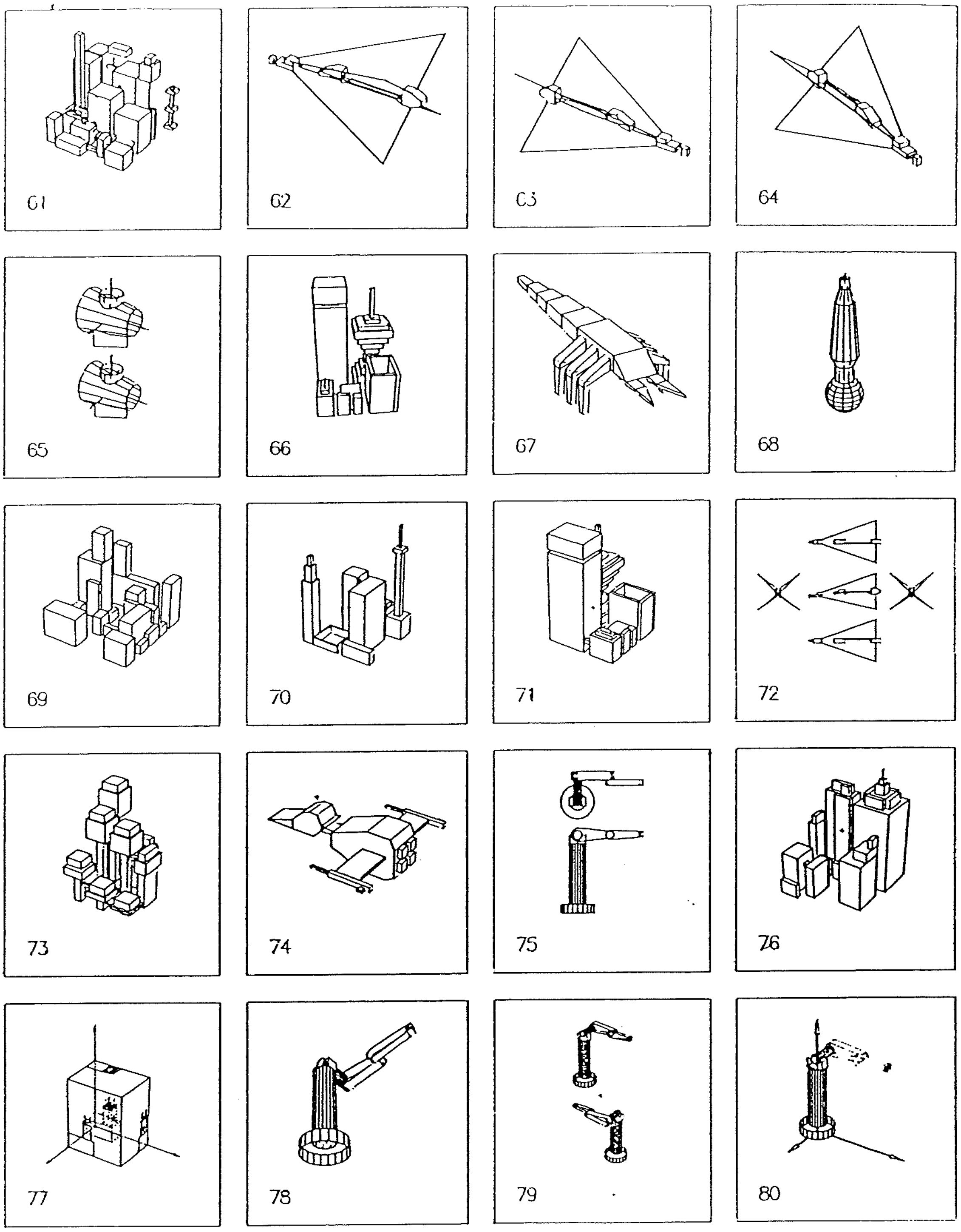
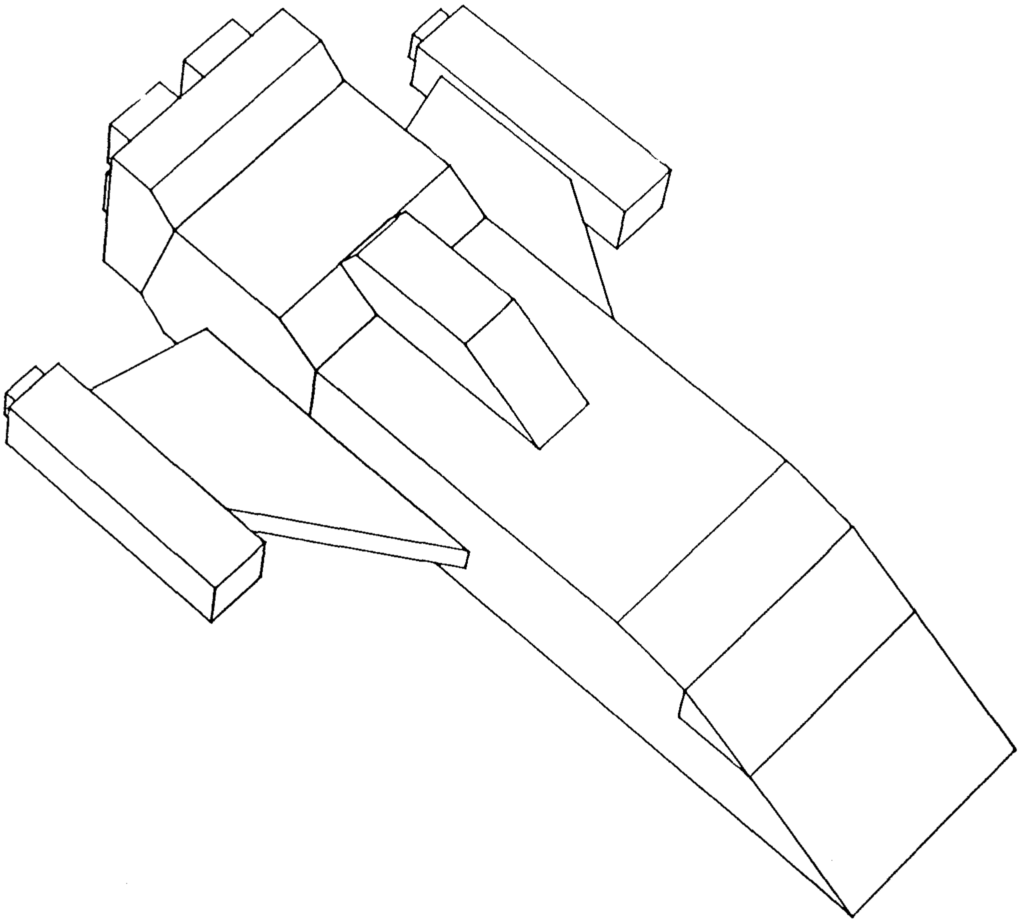
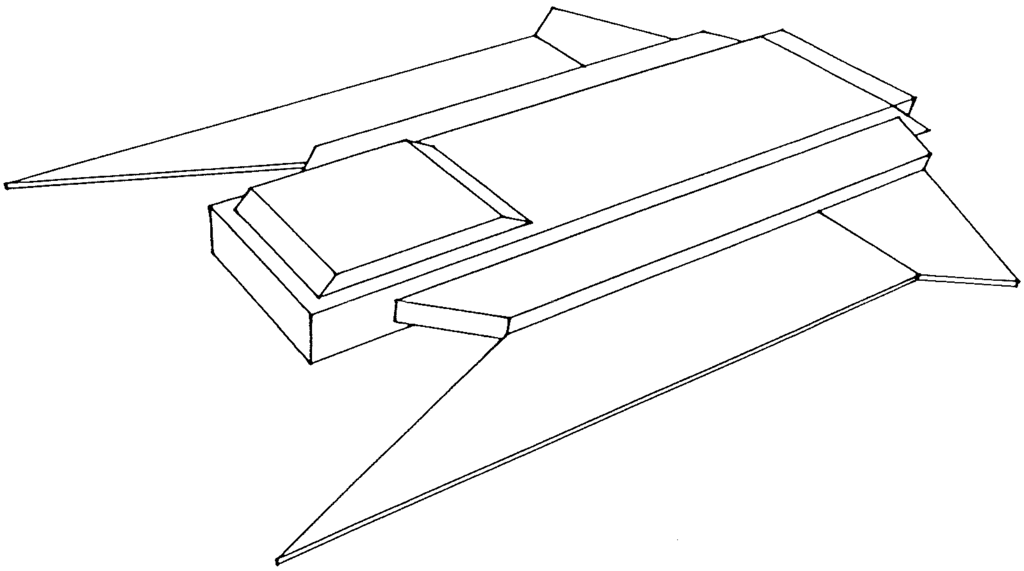


fig. 9. Last of the collection of plotfiles presented as examples. Note that text could have been included within each frame if required. Frame 67 is a view of a scorpion designed by Clive Carter



CREIGHTON TECHNICAL GRAPHICS			
TITLE	Spacecraft		
DESIGNER R.Burrough	TUTOR GROUP 2/9	DATE Nov 1981	
DRG NO	XX	DRG TYPE	Natural perspective
Drawn at Middlesex Polytechnic Computer Centre		DATE	27th July 1982

fig. 10. Spacecraft designed by a 2nd year in the technical graphics club.



CREIGHTON TECHNICAL GRAPHICS					
TITLE	Vogon Cruiser				
DESIGNER	C.Hughes	TUTOR GROUP	2/9	DATE	19th May 1982
DRG NO	PCH001	DRG TYPE	N.Persp. R330,E45,D60		
Drawn at Middlesex Polytechnic Computer Centre				DATE	19th May 1982

fig. 11. Spacecraft designed by a 2nd year in the technical graphics club.

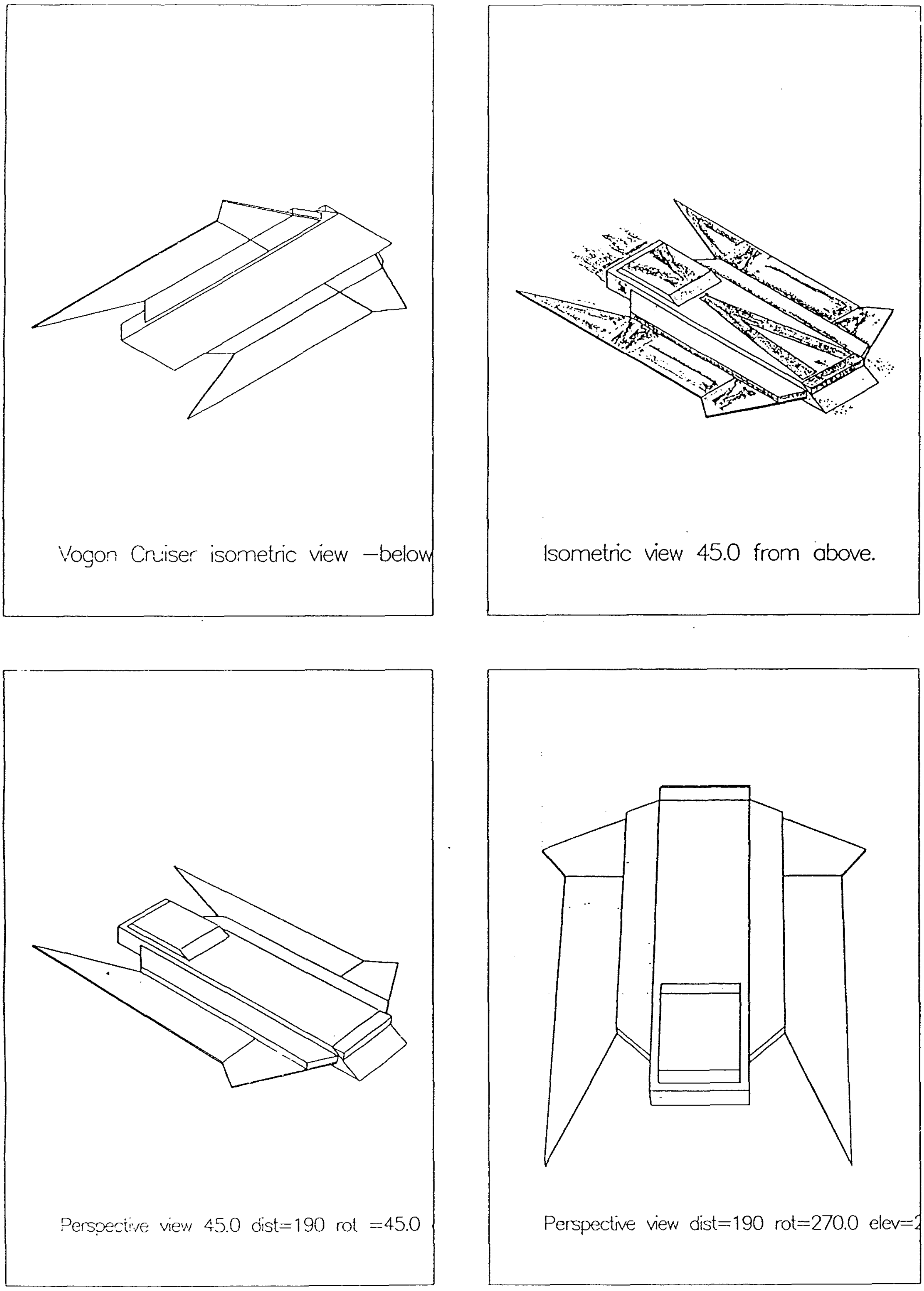
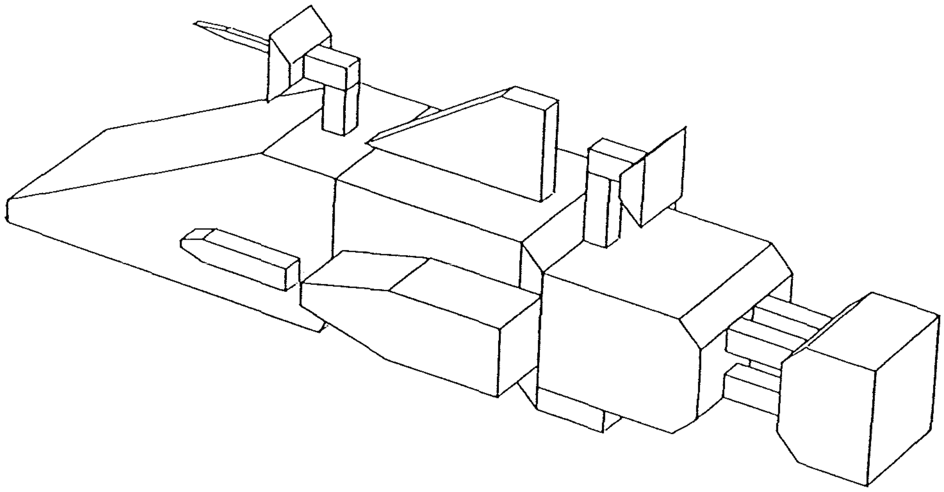


fig. 12. Four different views of the Vogon Cruiser designed by Chris Hughes who also coloured one of the views by hand, just one of the possible further uses which may be made of a computer produced drawing.



CREIGHTON TECHNICAL GRAPHICS

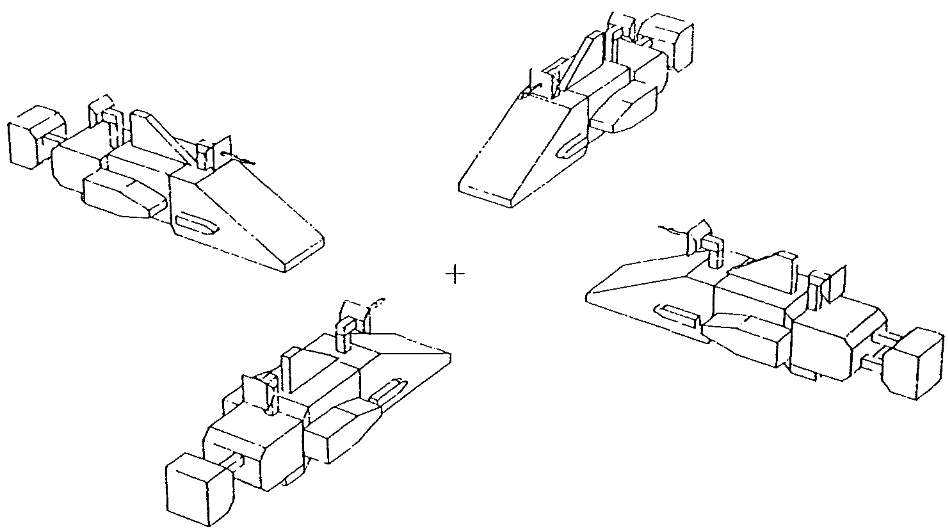
TITLE Spacecruiser 1

DESIGNER O.Haralambous TUTOR GROUP 3/115 DATE 18th June 81

DRG NO POH001 DRG TYPE Pictorial view

Drawn at Middlesex Polytechnic Computer Centre DATE 20th July 81

Fig. 13. Spacecraft design by Olga Haralambous, a 3rd-year, during technical drawing drawing lesson time.

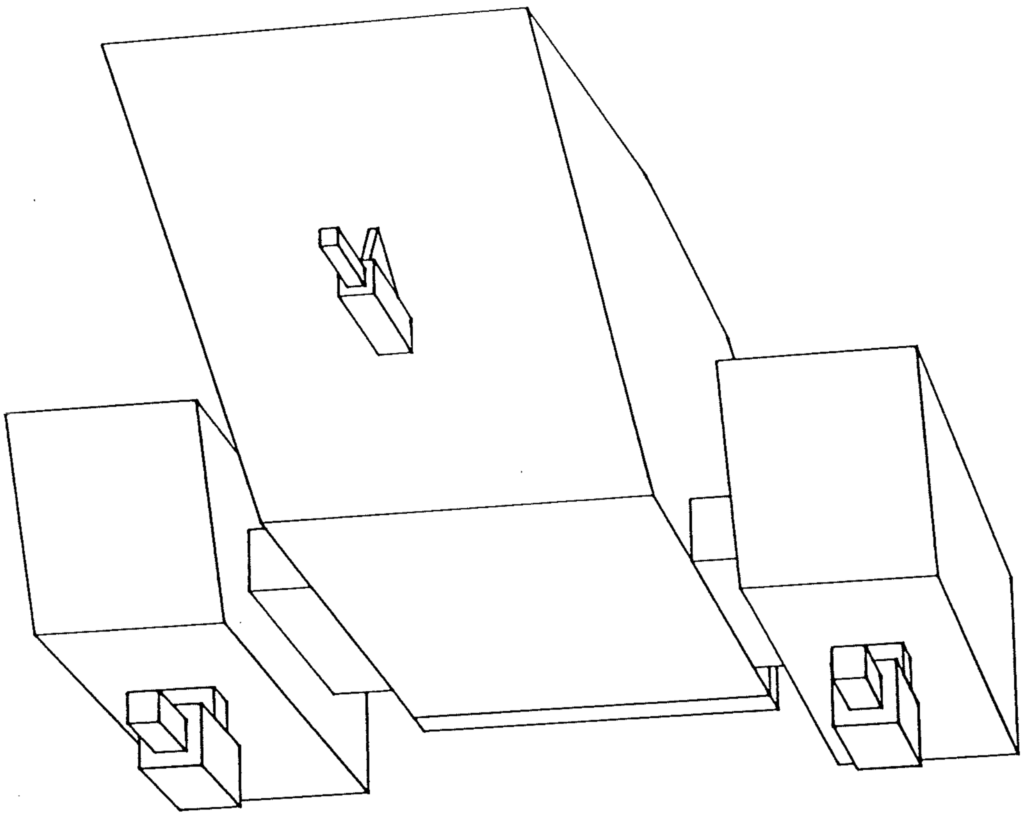


CREIGHTON TECHNICAL GRAPHICS

TITLE	Spacecruiser 1
DESIGNER	O.Haralambous TUTOR GROUP 3/115 DATE 18th June 1981
DRG NO	POH4V1 DRG TYPE Pictorial view

Drawn at Middlesex Polytechnic Computer Centre DATE 31st July 1981

Fig. 14. Drawing showing a spacecraft rotated by 90 degree increments. Just one of the possible ways in which spatial concepts may be explored.

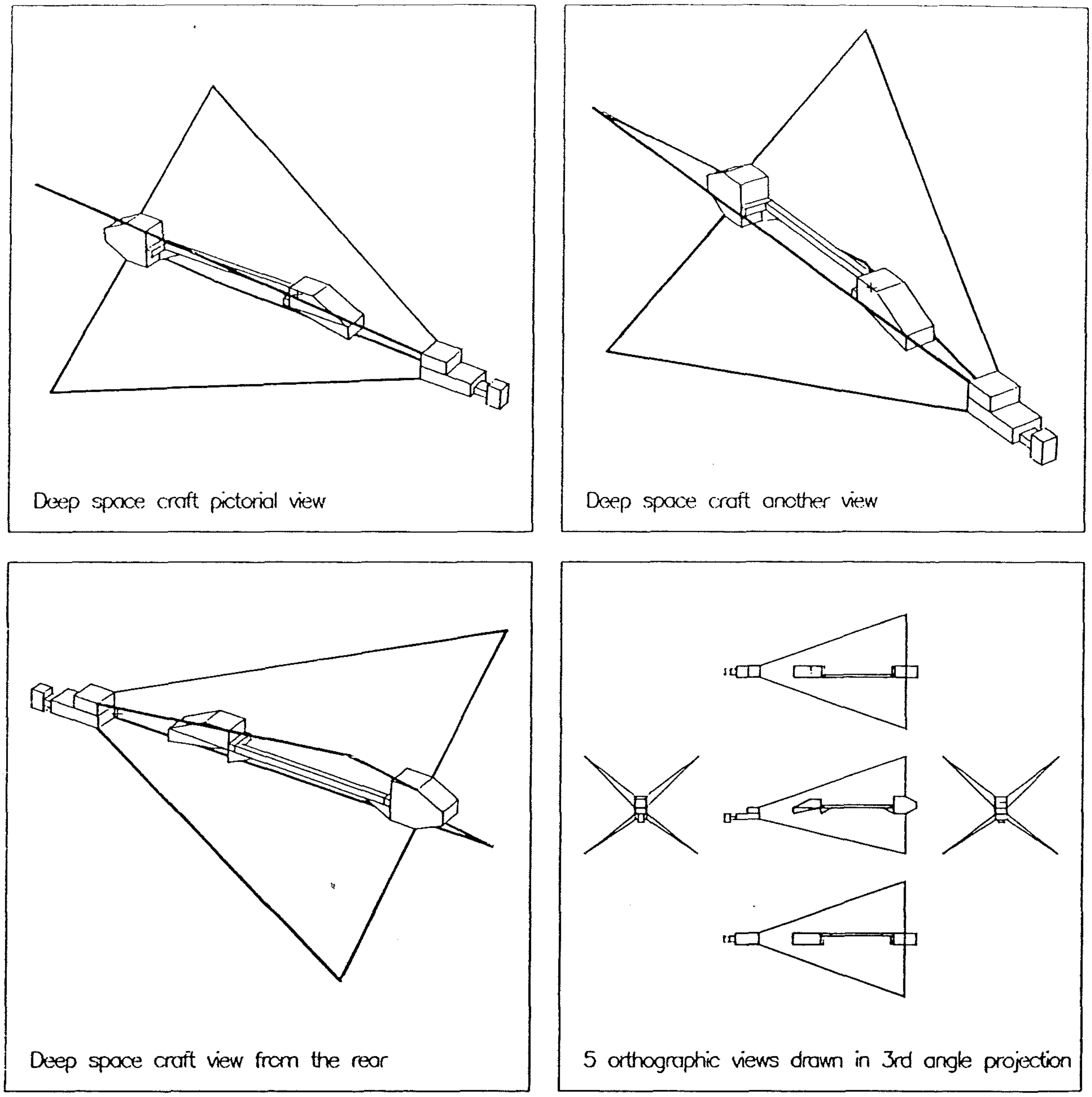


Creighton Technical Graphics

Title	Hell's Messenger				
Designer	T.Watson	Tutor Group	6/H	Date	July 1982
Drg NO	5	Drg Type	N.persp D=100, R=285, E=345		

Drawn at Middlesex Polytechnic Computer Centre   Date   30th July 1982

fig. 15. A design by a 6th-year created in the Technical Graphics Club



Deep space craft

The space craft above was designed by **Terence Watson** sixth form pupil (1982) at **Creighton School** (now Fortismere School). The school is situated in the London borough of Haringey. The computer program designed by **G.A.Edwards** synthesizes the craft from data that has been taken from plan and elevations.

3D Computer Graphics

Fig. 16. A poster for an exhibition of work carried out in Haringey schools. This design was realised only after the subroutine LNE3D had been written, enabling the long struts to be synthesised as PICASO type objects.

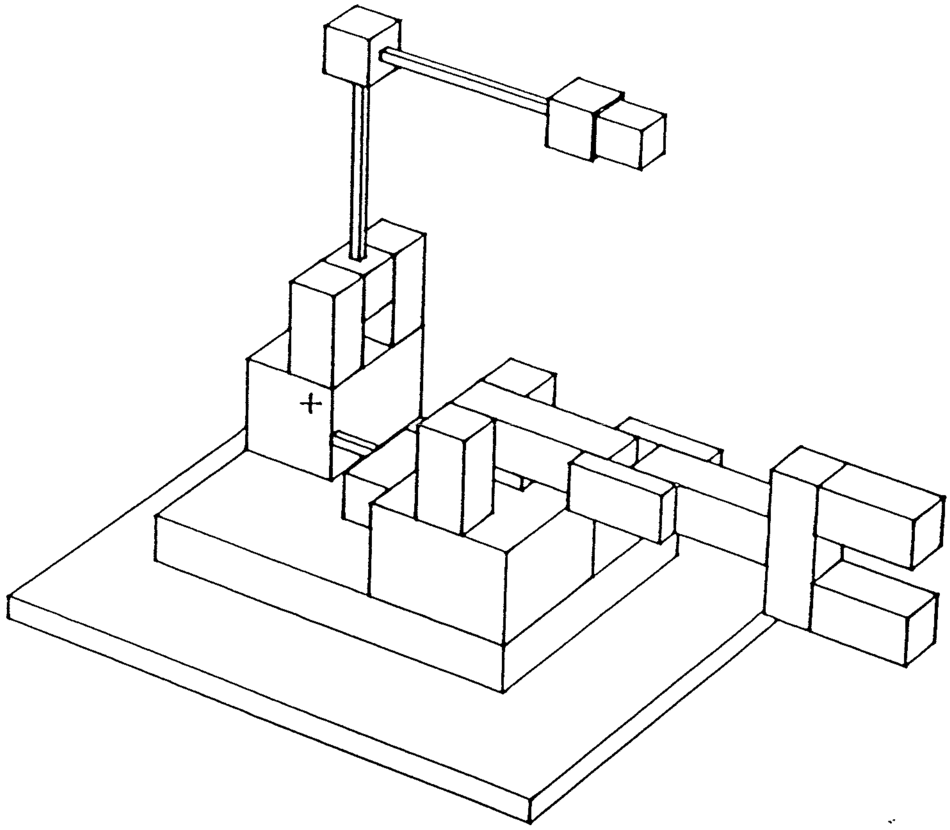


Fig. 17. A 3rd-year robot design that has moving parts. See also fig. 18 and fig. 1.

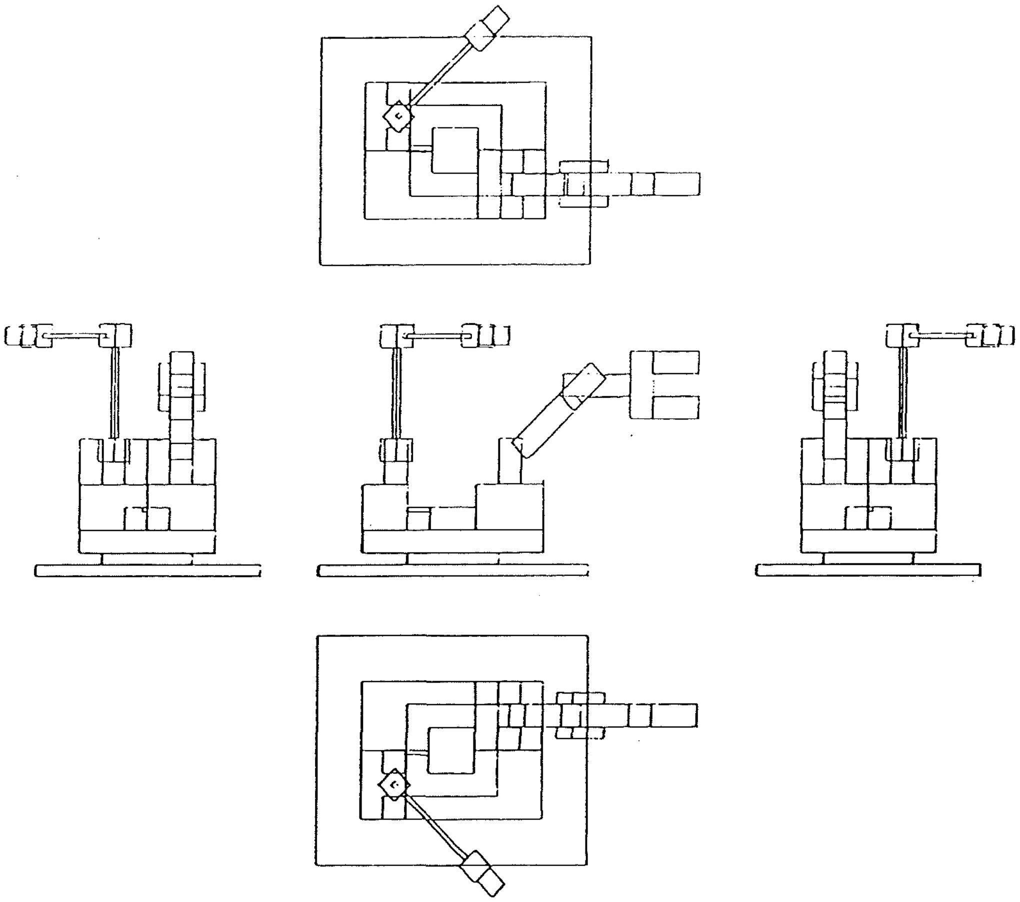


fig. 18. Five orthographic views of Howard Peter's robot showing rotation of the arms. Several drawings could be generated similar to this one with varying rotation to help pupils understand the foreshortening effect of rotation in the orthographic views.

maximum amount of rotation

Your name and tutor group	Project title	Drg No
~~[illegible]~~ HOWARD PETERS 3/18	ROBOT	14 12 82

	Part (24)	width X	height Y	depth Z	coordinates of corner Xcoord	Ycoord	Zcoord
	1	12	0.5	10	0	0	0
	2	4	0.5	~~16~~ 4	4	0.5	3
	3	8	1	6	2	1	2
	4	2	2	3	2	2	2
	5	1	0.2	0.2	4	2.8	4.8
	6	2	1	2	5	2	4
	7	3	2	3	7	2	5
	8	1	2	1	3	4	4
	9	1	2	1	8	4	7
ARM4	10	2 34	1	1	8 8 9	5	6
	11	2	1	0.5	11	5	7
	21	2	1	0.5	11	5	5.5
ARM2	12	3	1	1	13	5	6
	13	1	3	1	15	4	6
	14	2	1	1	16	6	6
	15	2	1	1	16	4	6
	22	1	2	1	8	4	5
	23	1	2	1	3	4	2
ARM3	16	0.2	4	0.2	3.4	6	3.4
	17	1	1	1	3	10	3
	18 Platform	4	0.2	0.2	4	10.4	3.4
	19	1	1	1	8	10	3
	20	1	0.8	0.8	9	10.1	3.1
	24	1	1	1	3	5	3

Computer aided design Cuboid data

CAD 007 Complete Robot

(11)

fig. 19. A typical cuboid data sheet for the robot in figs. 17-18. Marks visible on the sheet show checking and correction of data, and indication of the groups of cuboids which form the components that may be rotated as sub-assemblies.

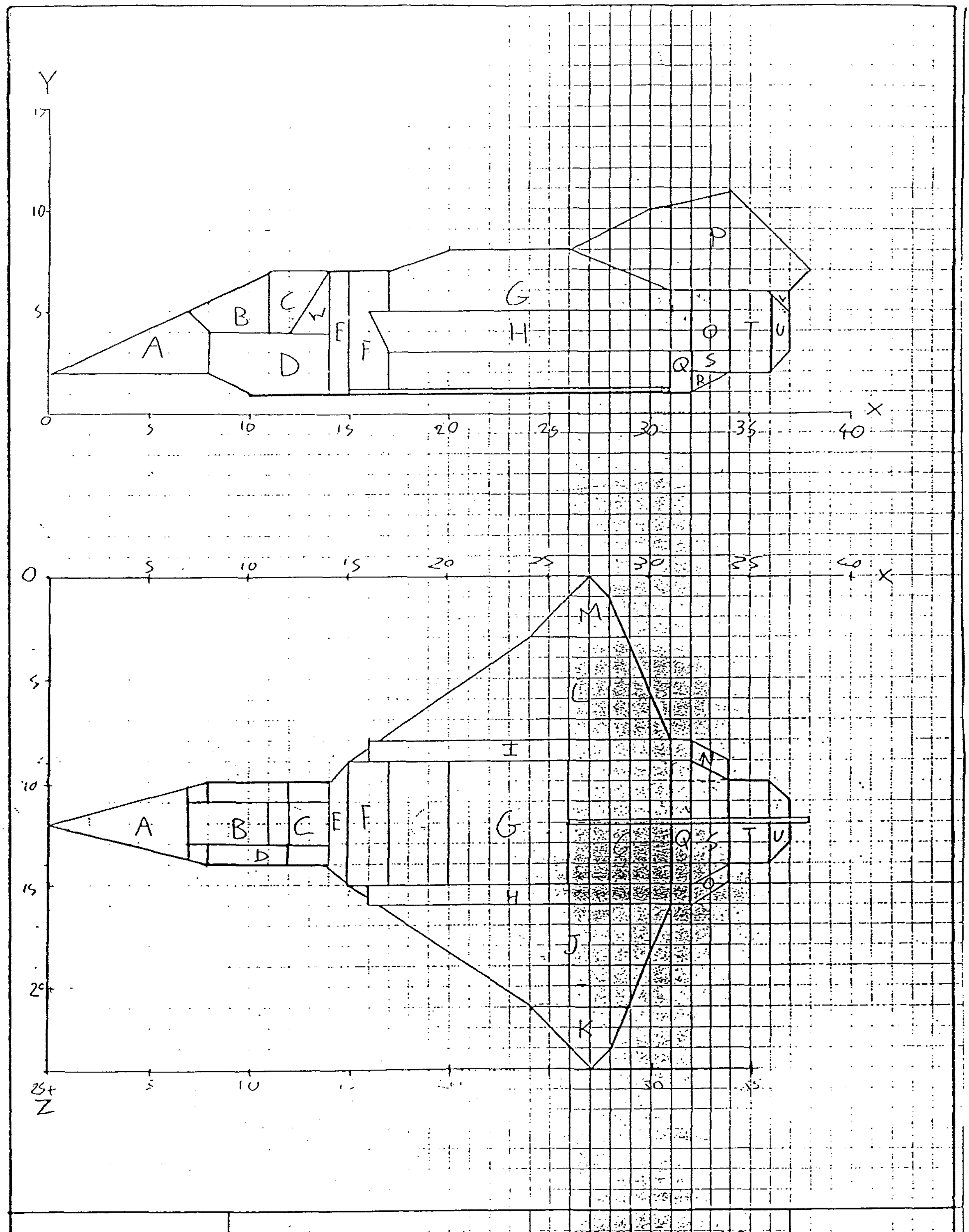


Fig. 20. Spacecraft design by Howard Peters. This design was difficult due to a relatively complex nose. Initially there was one or two errors in the drawing that had to be resolved by means of pictorial sketches, see figs 21-22.

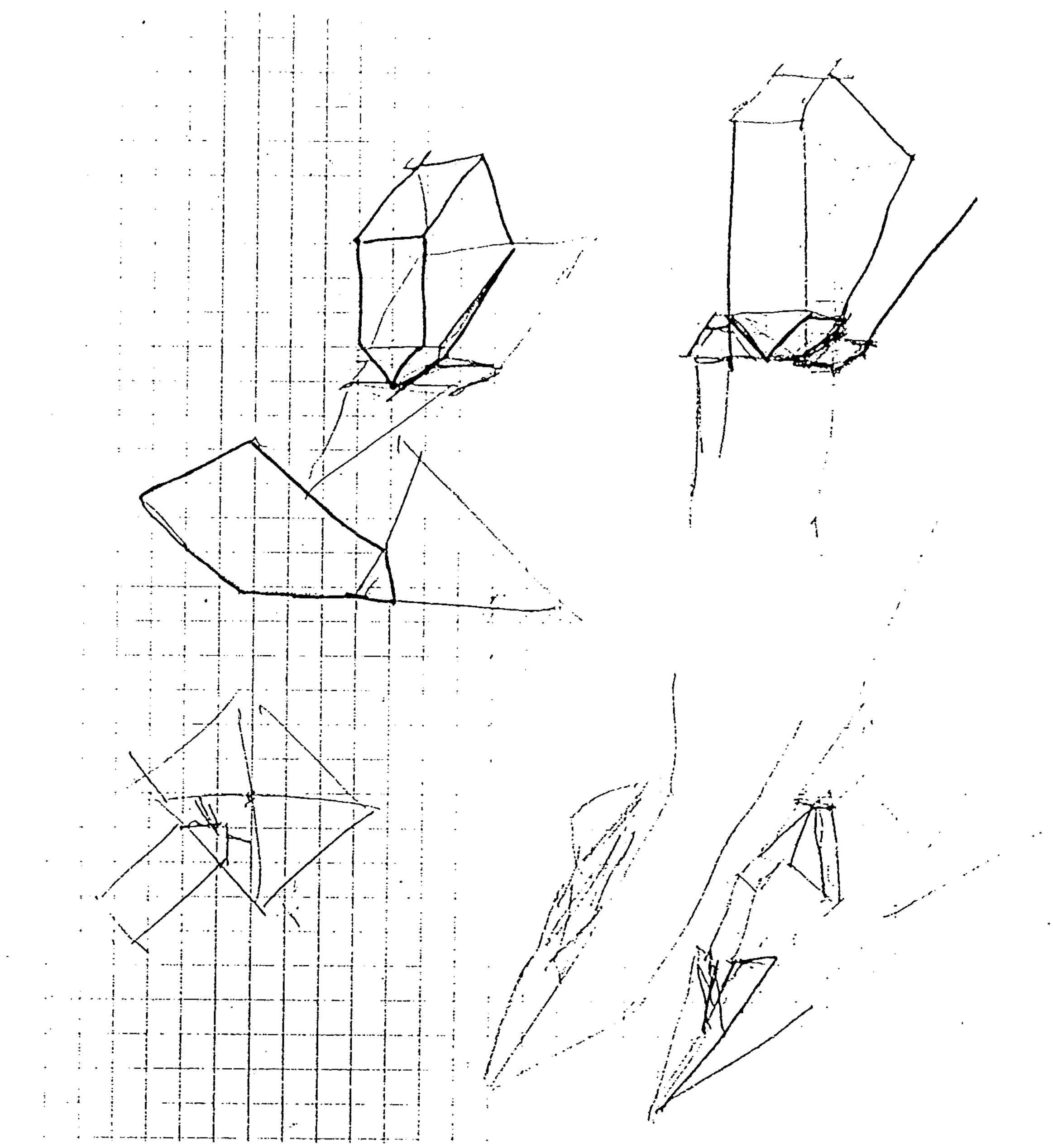


Fig. 21. Pictorial sketches made by the pupil to help communicate his concept of the geometry of the nose of the spacecraft. Note how relatively inadequate such sketches are, particularly as there is no attempt by the pupil to make use of the square grid paper. See also fig. 22.

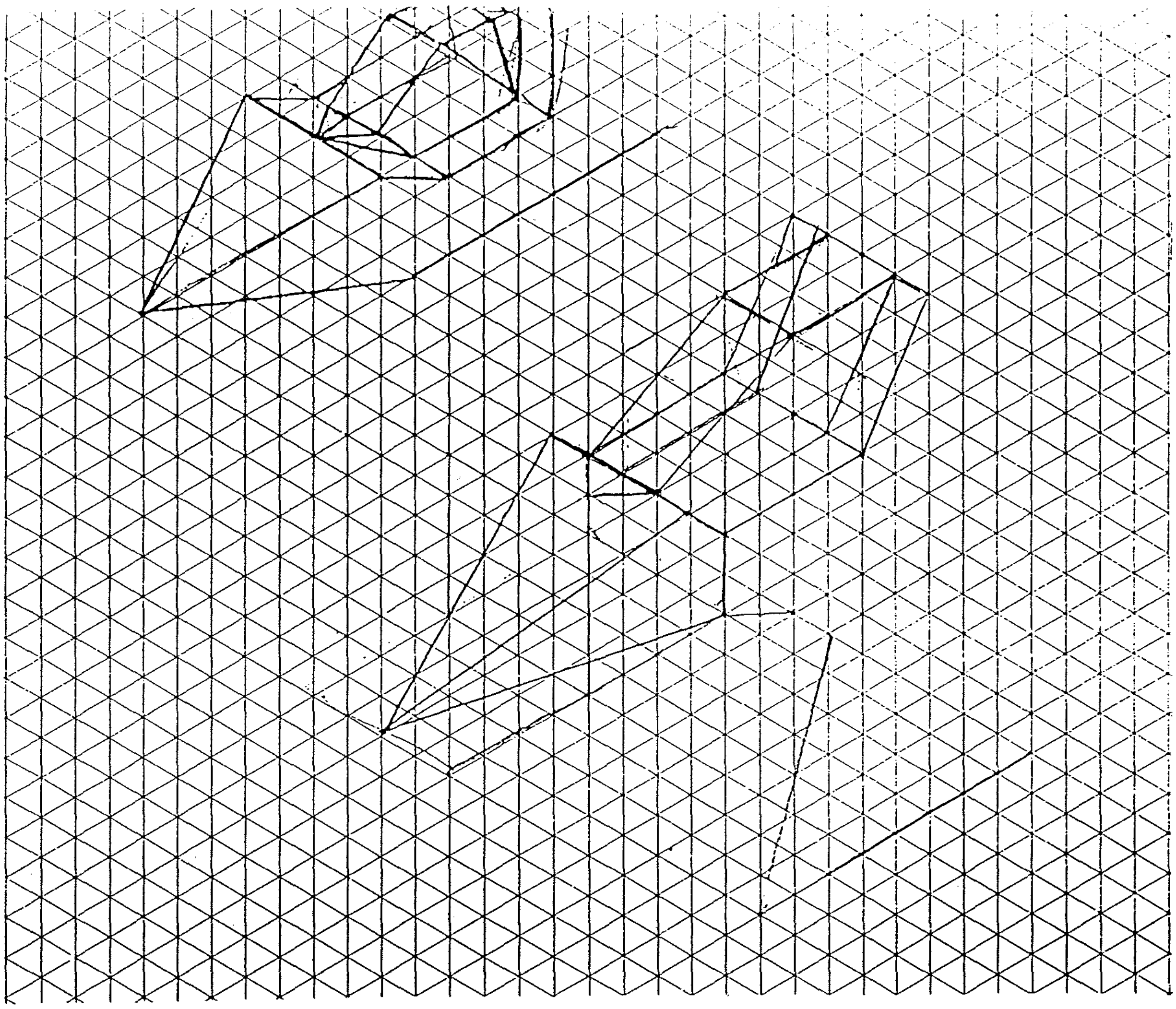


Fig. 22. Isometric type pictorial sketches by the author to ensure that that the pupil's design of the spacecraft nose is as described in fig. 21. The sketches were made whilst engaged in a dialog with the pupil. It should be noted that the pupil had only made a slight error in the original orthographic views, and that a prismatic nose form as stipulated by the Spacecraft Project brief would have spoilt the pupil's design concept.

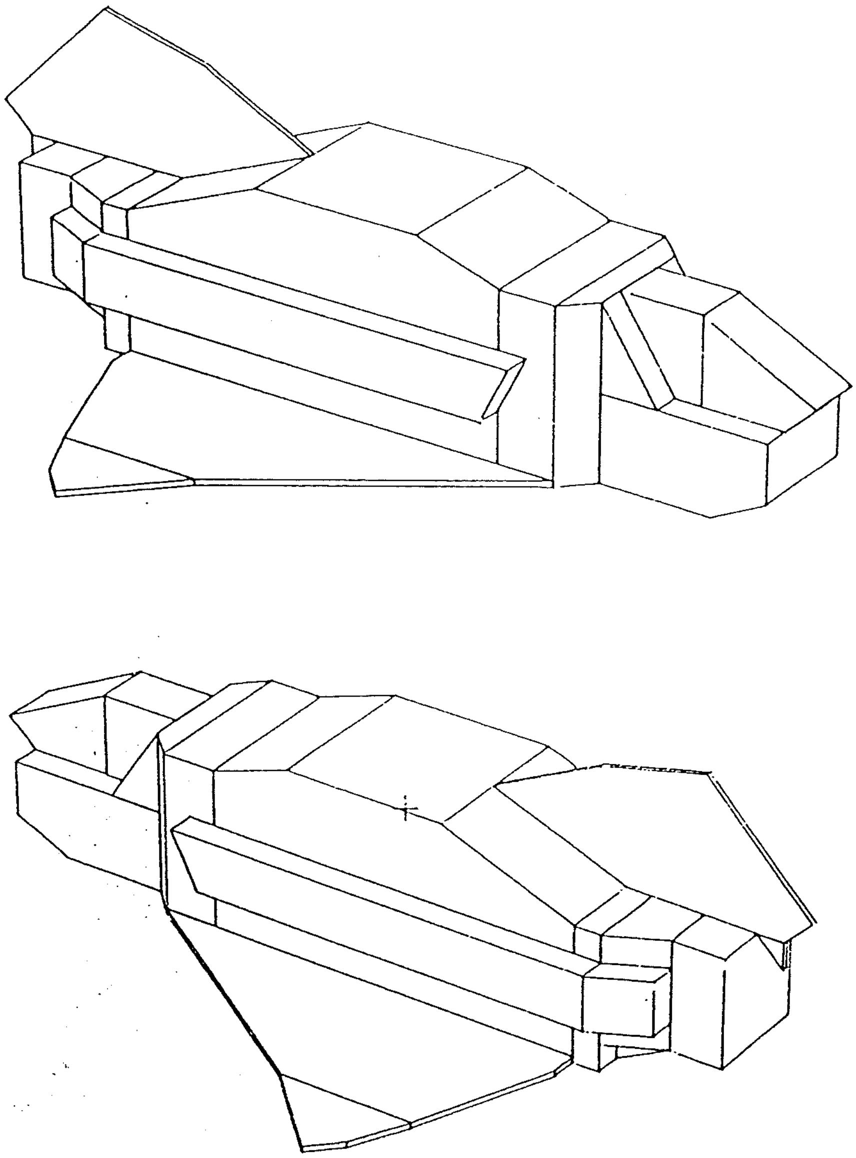
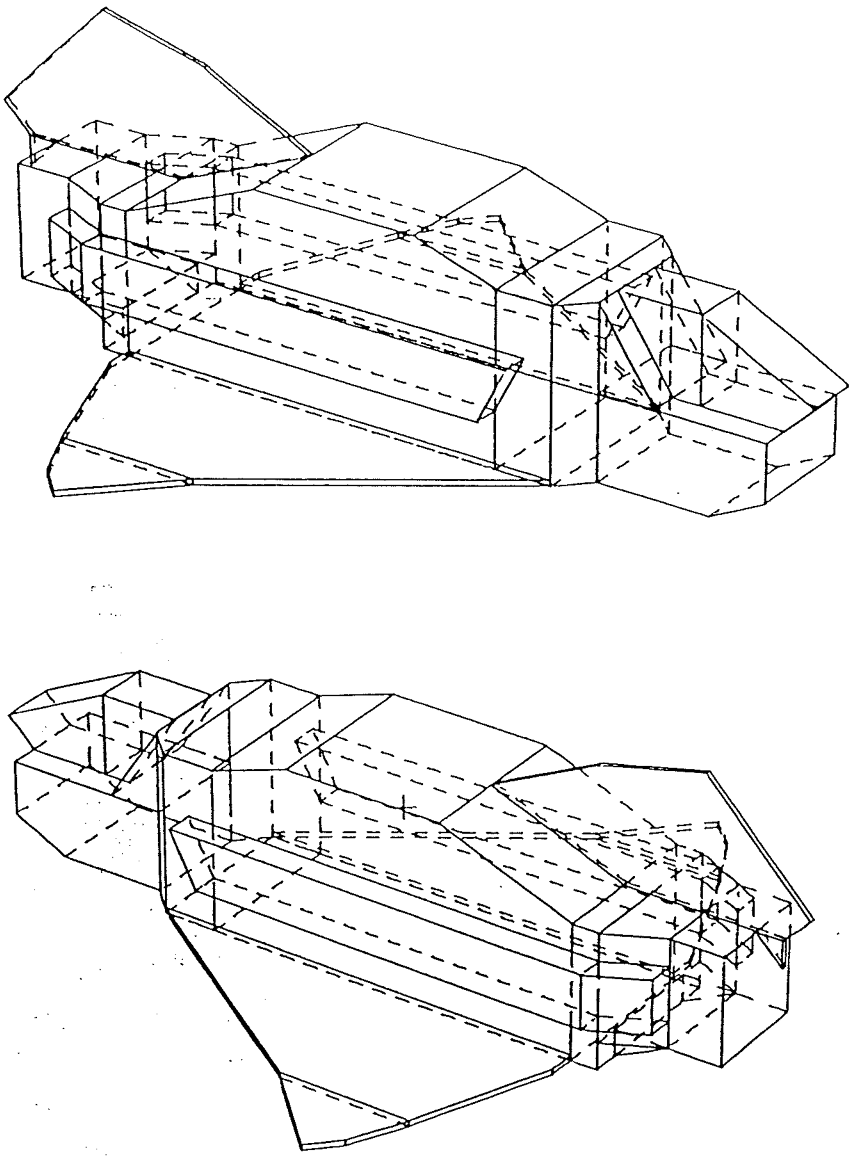


fig. 23. Two perspective views of Howard Peters' spacecraft drawn without the nose to check the accuracy of the data.



Howards' spacecraft

A hidden detail computer generated drawing.
4,000 XY coordinate points at least! Drawn in less than 30 seconds!
Draw on a Calcomp 960 graph plotter at Middlesex polytechnic.

Fig. 24. Drawing showing the complexity of hidden detail in a perspective view. The legend refers to the time used to plot the drawing but neglects to mention the amount of time used to generate the views, which was considerably longer.

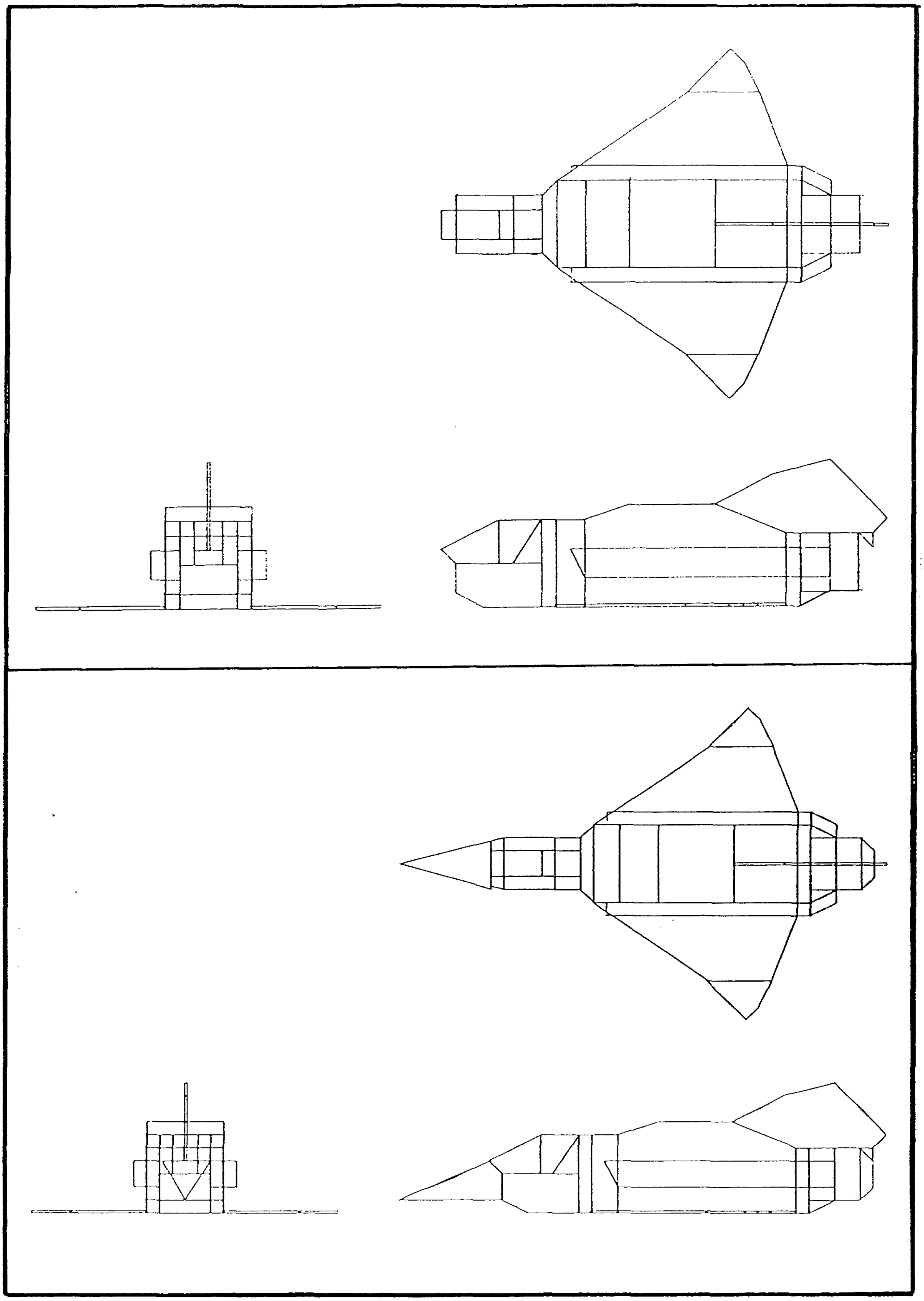


fig. 25. Two orthographic drawings of Howard Peters' spacecraft without the nose and complete with the nose.

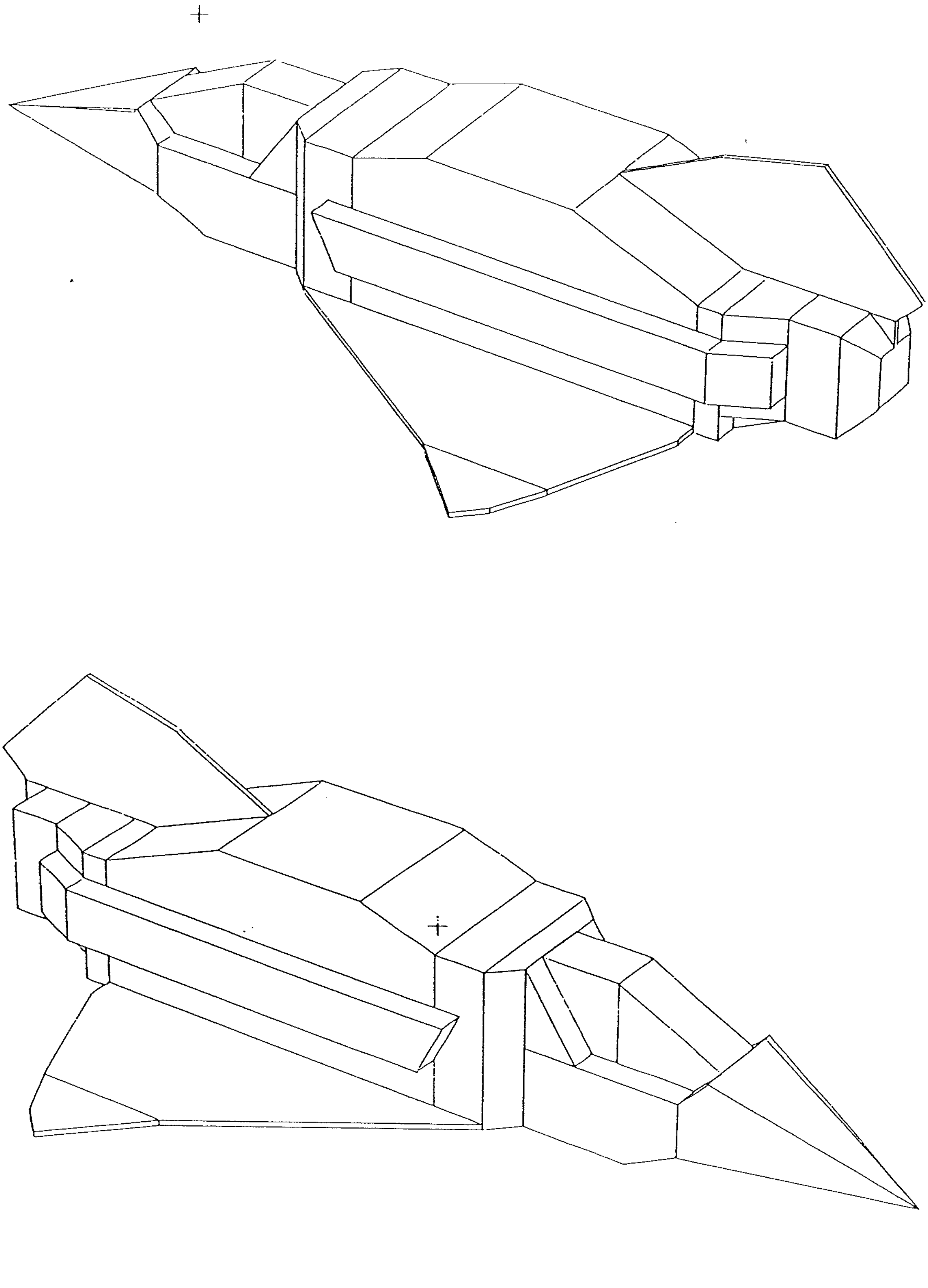


fig. 26. Two perspective views of Howard Peters' spacecraft rotated 180 degrees, these views reveal an error in the data for the nose that is not so easily noticed in the orthographic views.

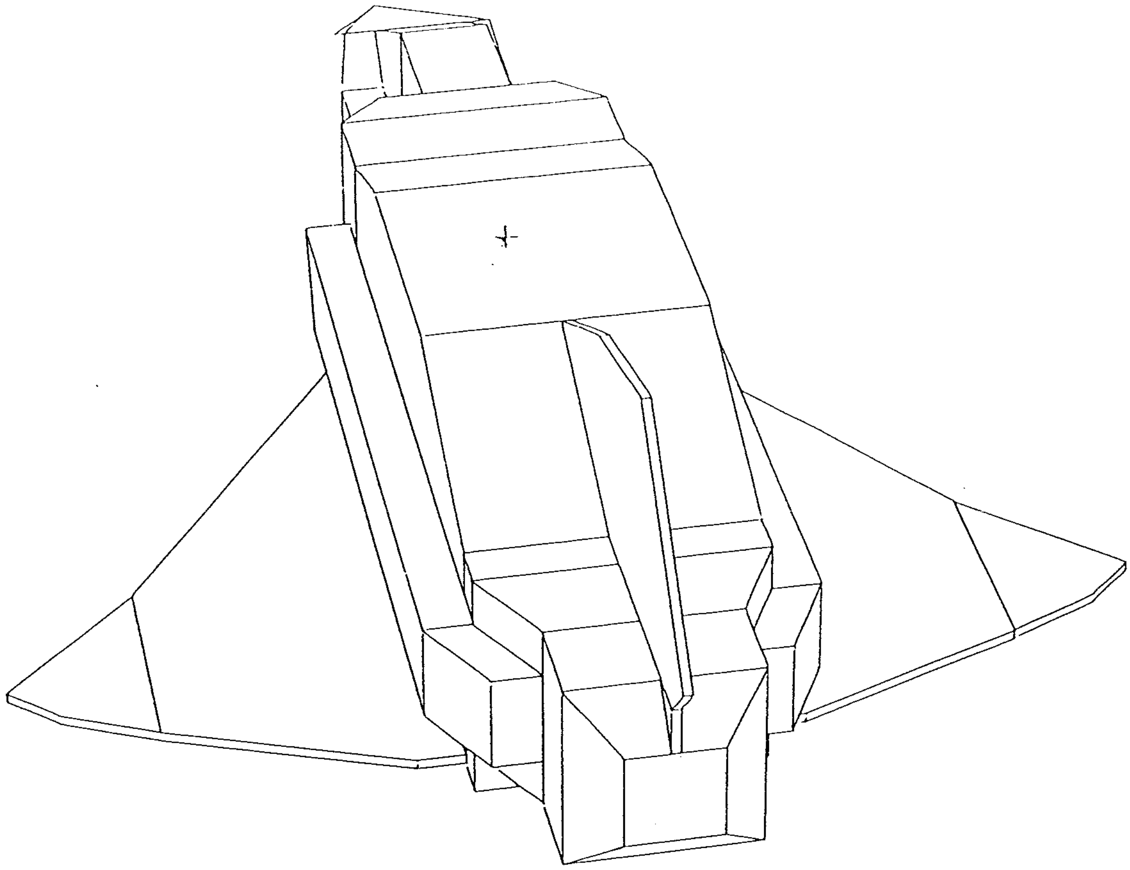


fig. 27. Perspective view of the rear of Howard Peters' spacecraft

"HP0002"

Your name and tutor group	Project title	Drg No
HOWARD. PETERS. 3/18.	SPACESHIP 4.	121082

A	D		
~~[illegible]~~	Z	YTHICK=6	17,3
~~8,14~~	14,7	YDIST=7	16,5 DA3008
~~[illegible]~~	14,1		EOL DAT008
~~[illegible]~~	10,1	G	EOS
~~[illegible]~~	8,2	Z	ZTHICK=1
~~[illegible]~~	8,4	17,2	ZDIST=9
~~[illegible]~~	12,4	20,8	
	14,7	26,8	J
B	EOL	31,6	Y
Z	EOS DA3003	31,1	15,15
11,7	ZTHICK=4	17,1	31,15
11,4	ZDIST=14	17,7 DA3006	31,16
8,4	DAT003	EOL DAT006	24,21
7,5	E	EOS	24,21
11,7 DA3001	Y	ZTHICK=6	15,15
EOL DAT001	15,9	ZDIST=15	EOL
EOS	15,15		EOS DA3009
ZTHICK=2	14,14	H	YTHICK=0·2
ZDIST=13	14,10	Z	YDIST=1·2
	15,9 DA3004	16,5	DAT009
C	EOL DAT004	32,5	K
Z	EOS	32,3	Y
14,7	YTHICK=6	17,3	24,21
12,4	YDIST=7	16,5 DA3007	29,21
11,4		EOL DAT007	28,23
11,7	F	EOS	22,24
14,7 DA3002	Y	ZTHICK=1	24,21
EOL DAT002	15,9	ZDIST=16	EOL
EOS	17,9		EOS
ZTHICK=2	17,15	I	YTHICK=0·2
ZDIST=13	15,15	Z	YDIST=1·2
	15,9 DA3005	16,5	DA3010
	EOL DAT005	32,5	DAT010
	EOS	32,3	

P.T.O. SPLIT INTO 2 PARTS

Computer aided design Prism data

PTO

fig. 28. Data sheet for Howard Peters' spacraft. Note the data is continued overleaf.

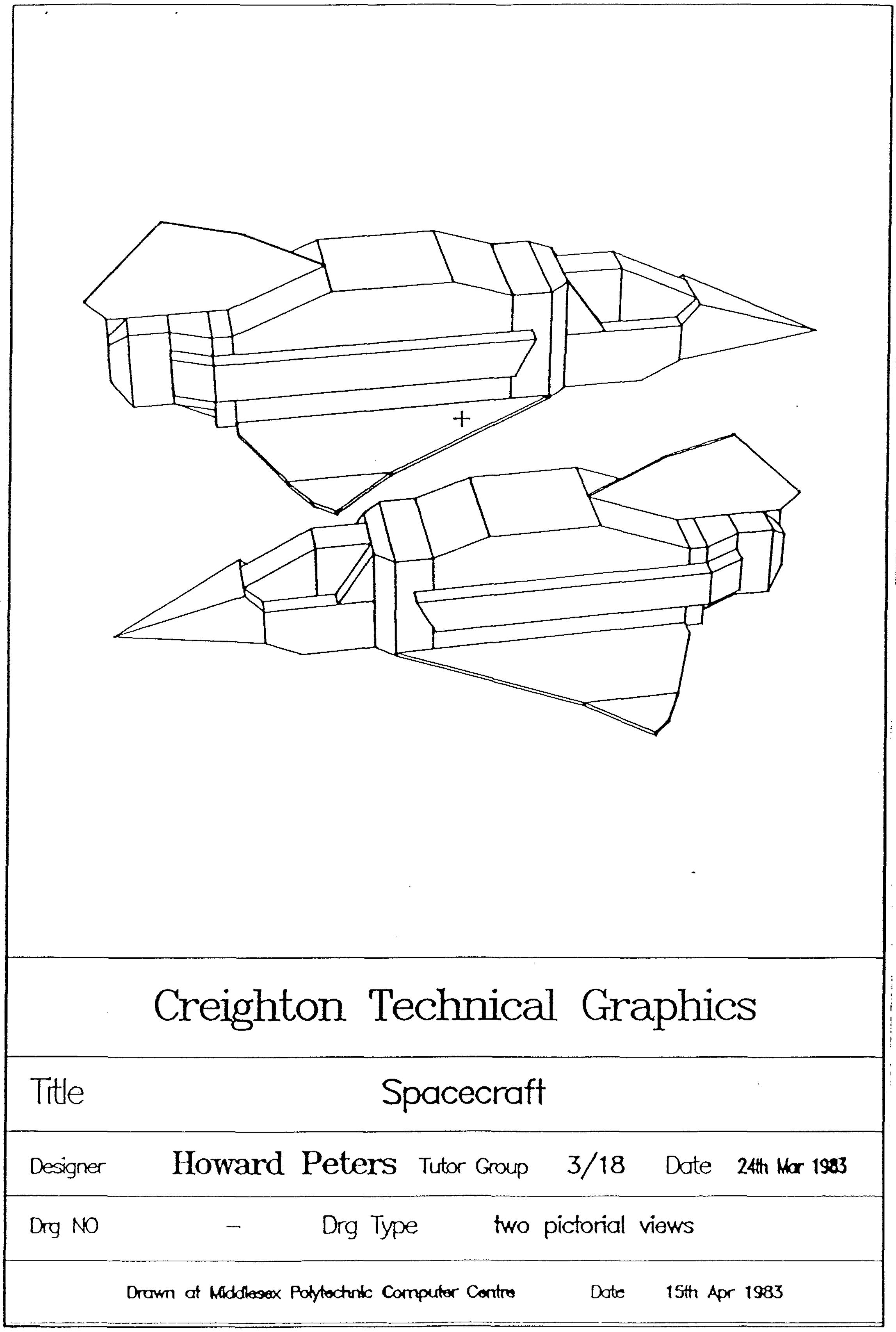


Fig. 29. Two error-free perspective views of Howard's spacecraft plotted with the usual identification data.

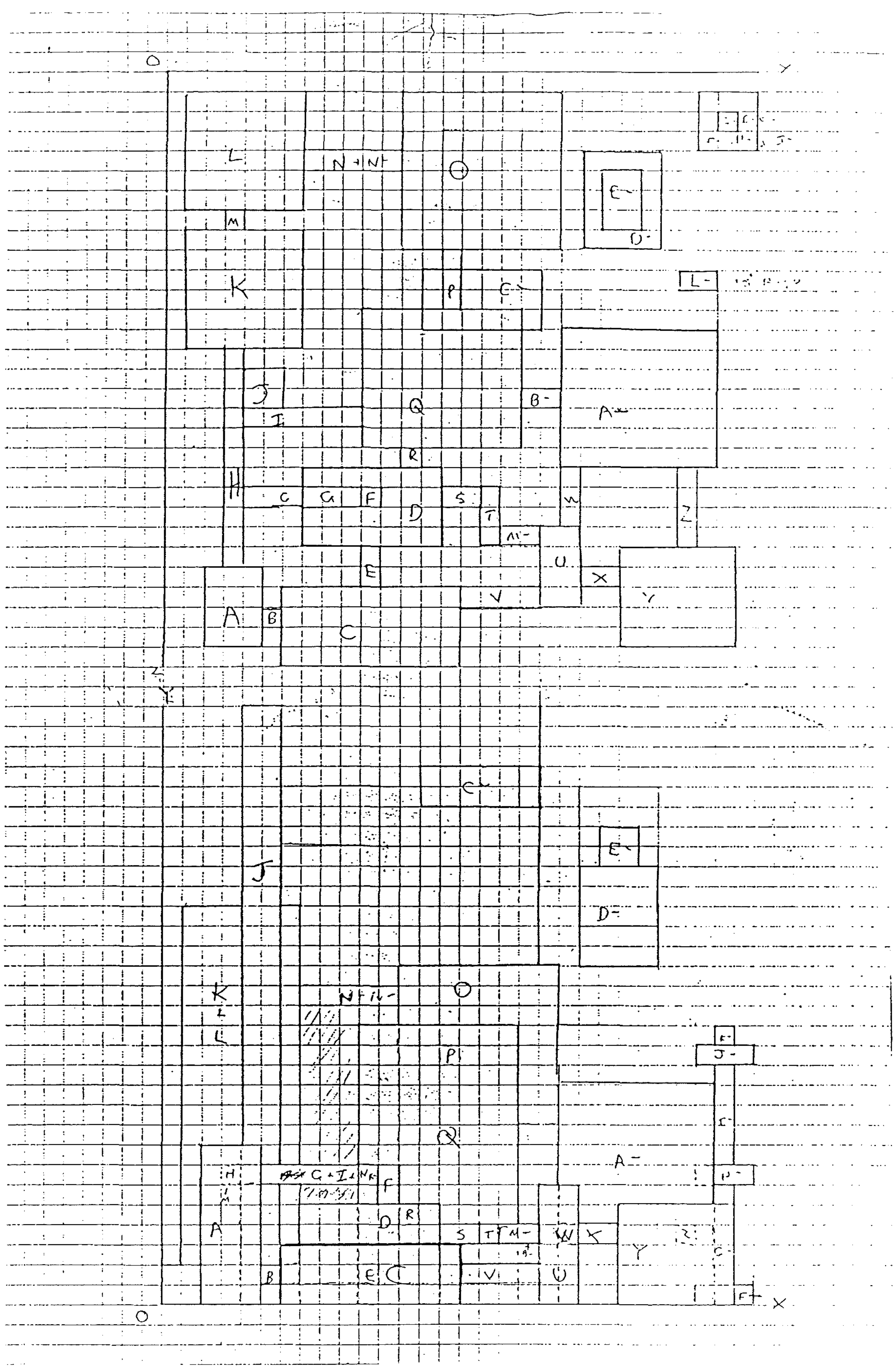


fig. 30. City Unit Project example by Thomas Heathcote, a 3rd-year pupil. The original drawing is on A3 size square grid paper.

Your name and tutor group	Project title	Drg No
THOMAS [illegible]	[illegible]	[illegible]

Part	width x	height y	depth z	coordinates of corner Xcoord	Ycoord	Zcoord
A	3	5	4	2	0	25
B	1	1	1	5	1	27
C	9	3	4	6	0	26
D	7	5	4	7	0	20
E	1	1	2	10	1	24
F	1	2	1	10	5	21
G	6	1	1	4	6	21
H	1	1	11	3	6	14
I	6	1	1	4	6	17
J	2	30	2	4	0	15
K	6	20	6	1	0	8
L	6	20	6	1	0	1
M	1	1	1	3	6	7
N	5	1	1	7	15	4
O	5	17	8	12	0	1
P	1	1	3	14	12	9
Q	5	14	7	10	0	12
R	1	1	1	12	4	17
S	2	1	1	14	3	21
T	1	1	3	16	3	21

Notes: GENERAL HOUSING UNIT · UNPLANNED BLOCKS BUILT AT DIFFERENT TIMES; INTER BLOCK TRANSIT SYSTEM & WAS ORIGINALLY ON DIFFERENT LEVEL [illegible] HAVE BEEN CHANGED & ARE NOW [illegible] ON LEVELS 1, 3, & 6

Computer aided design Cuboid data

Fig. 31. Typical data sheet for a fairly complex City Unit project example. Reduced by 83 per cent. The poor quality of the copy is due to the data sheet being printed on tinted paper and the light tone of the pencil written data. The data is continued in fig. 32.

Your name and tutor group	Project title	Drg No
[illegible]	[illegible]	15.8/?3

Unit	Width x	height y	depth z	coordinates of corner		
				Xcoord	Ycoord	Zcoord
U	2	6	4	19	0	23
V	4	1	1	15	1	26
W	1	1	3	20	3	20
X	2	1	1	21	3	25
Y	6	5	5	23	0	24
Z	1	1	4	26	3	20
A -	8	11	7	20	0	13
B -	2	1	1	15	3	16
C -	6	2	3	13	25	10
D -	4	5	5	21	17	4
E -	2	2	3	22	22	5
F -	3	1	3	27	0	1
G -	1	5	1	28	1	2
H -	3	1	3	27	6	1
I -	1	5	1	28	7	2
J -	3	1	3	27	12	1
K -	1	1	1	29	13	2
L -	2	10	1	26	0	10
M -	2	1	1	17	3	23
N -	5	1	1	7	6	4

Notes: "0 B8319"
(792)

Computer aided design Cuboid data

Fig. 32. Continuation of data for a City Unit project design.

088319

088319
City Unit
Thomas Heathcote
Creighton/Fortismere School
3/2
18th Nov 1983
C3
40

3.	8.	4.	2.	0.	25.
1.	1.	1.	5.	1.	27.
9.	3.	4.	6.	0.	26.
7.	5.	4.	7.	0.	20.
1.	1.	2.	10.	1.	24.
1.	2.	1.	10.	5.	21.
6.	1.	1.	4.	6.	21.
1.	1.	11.	3.	6.	14.
~~2.~~ 6	1.	1.	4.	6.	17.
2.	30.	2.	4.	0.	15.
6.	20.	6.	1.	0.	8.
6.	20.	6.	1.	0.	1.
1.	1.	1.	3.	6.	7.
5.	1.	1.	7.	15.	4.
8.	17.	8.	12.	0.	1.
1.	1.	3.	14.	12.	9.
8.	14.	7.	10.	0.	12.
1.	1.	1.	12.	4.	19.
2.	1.	1.	14.	3.	21.
1.	1.	3.	16.	3.	21.
2.	6.	4.	19.	0.	23.
4.	1.	1.	15.	1.	26.
1.	1.	3.	20.	3.	20.
2.	1.	1.	21.	3.	25.
6.	5.	5.	23.	0.	24.
1.	1.	4.	26.	3.	20.
8.	11.	7.	20.	0.	13.
2.	1.	1.	18.	3.	16.
6.	2.	3.	13.	25.	10.
4.	5.	5.	21.	17.	4.
2.	2.	3.	22.	22.	5.
3.	1.	3.	27.	0.	1.
1.	5.	1.	28.	1.	2.
3.	1.	3.	27.	6.	1.
1.	5.	1.	28.	7.	2.
3.	1.	3.	27.	12.	1.
1.	1.	1.	28.	13.	2.
2.	10.	1.	26.	0.	10.
2.	1.	1.	17.	3.	~~27.~~
3.	1.	1.	7.	6.	4.

Fig. 33. Computer printout of Thomas Heathcote's data file for his City Unit design. Note the correction of errors, and the 6 lines identifying the data

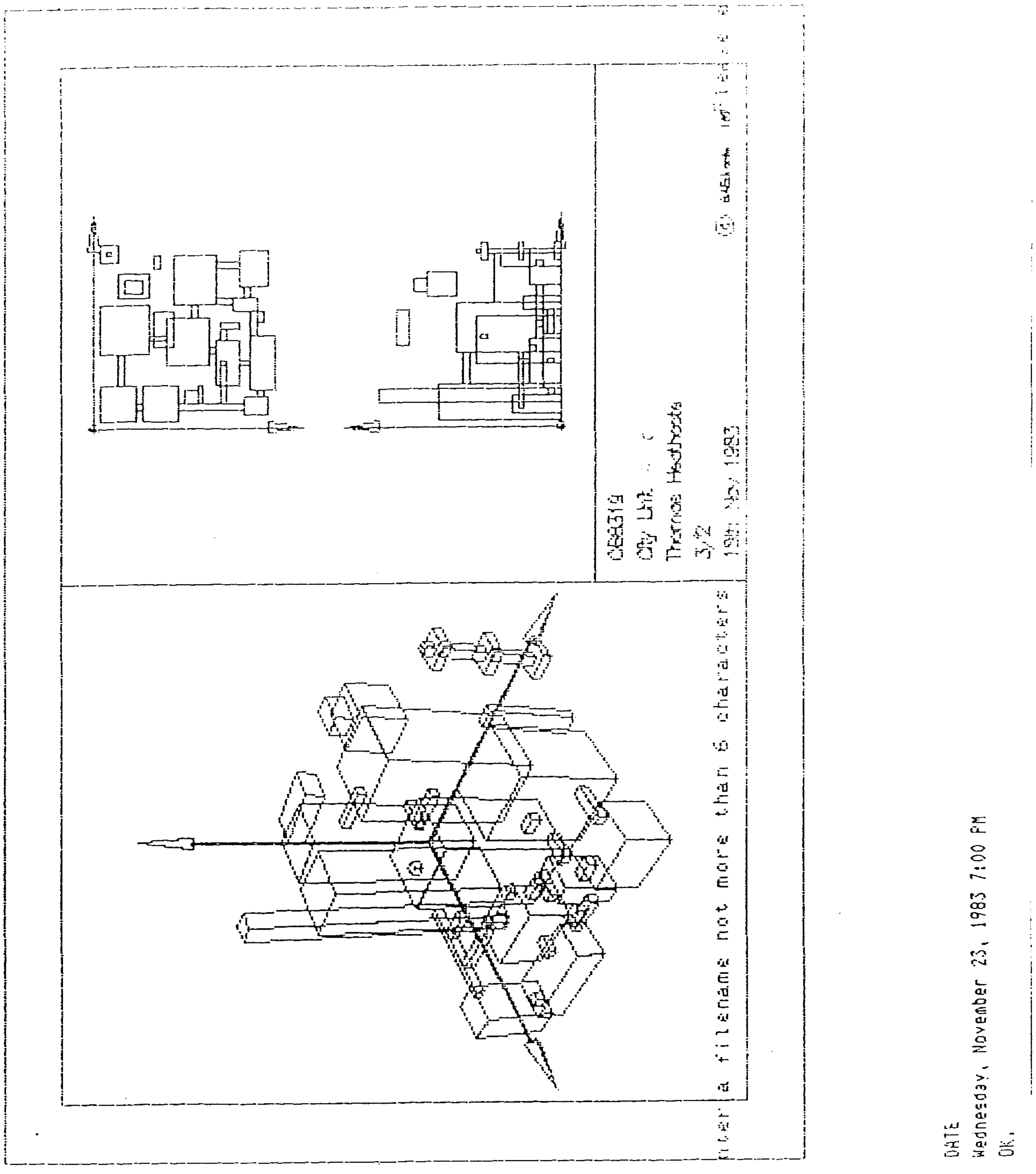


Fig. 34. VDU display screen copy of the drawing used to check whether Thomas' City Unit data was correct.

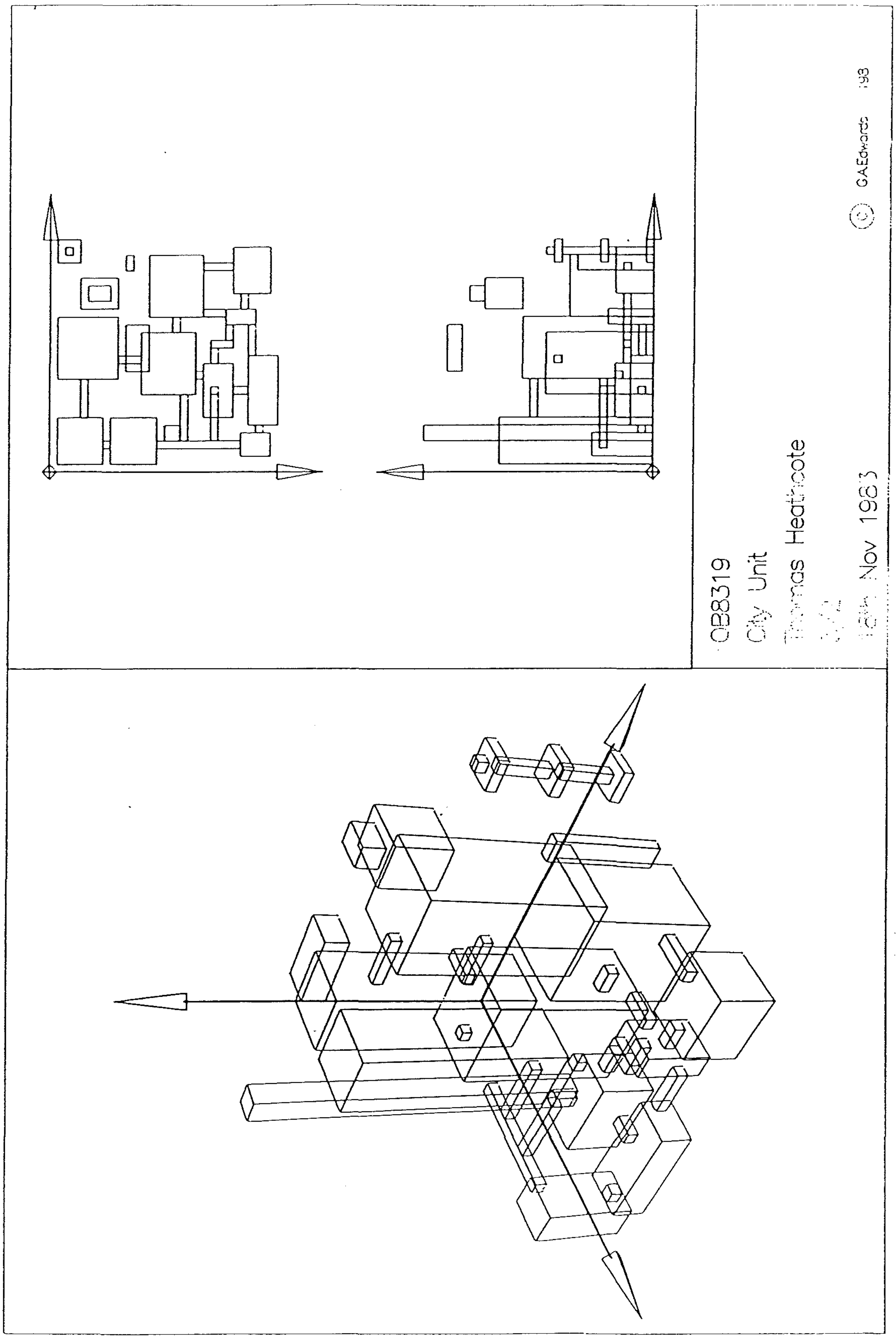
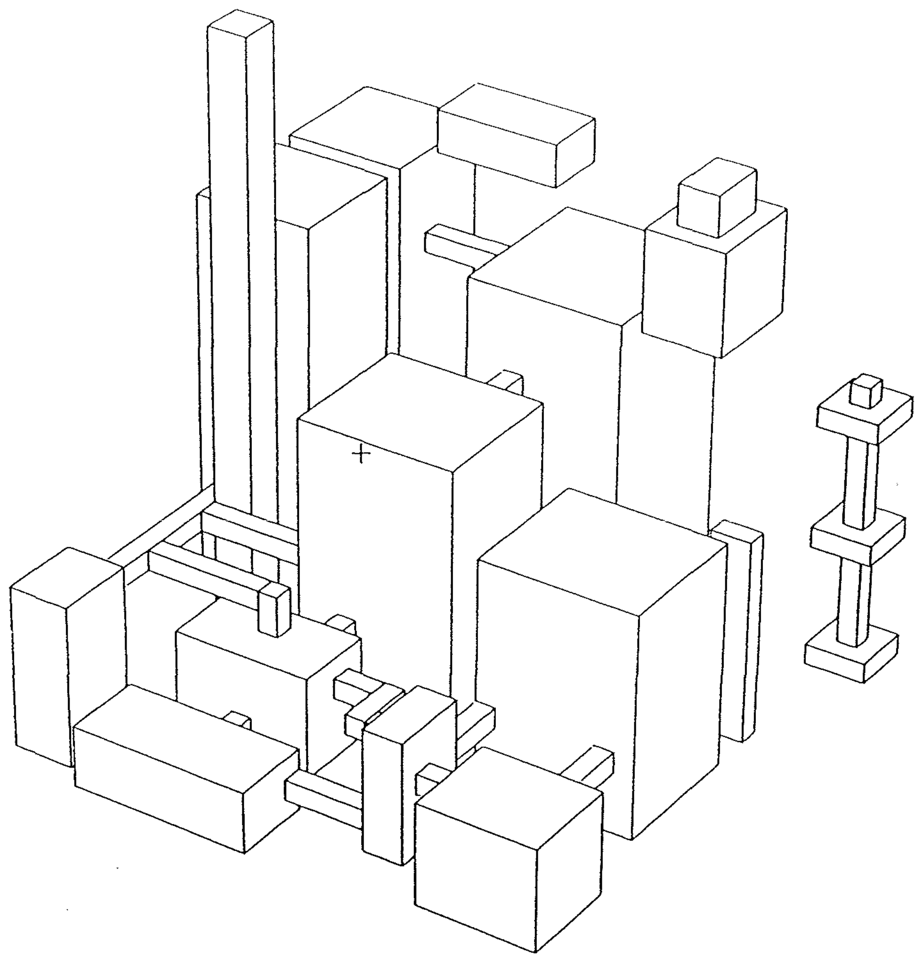


Fig. 35. Pictorial view and orthographic views of Thomas' City Unit design. The floating blocks are not errors.



Fortismere Technical Graphics

Title	City Unit 1

Designer Thomas Heathcote Tutor Group 3/2 Date 18th Nov 1983

Drg NO PGE061 Drg Type Natural perspective view

Drawn at Middlesex Polytechnic Computer Centre Date 17th May 1984

Fig. 36. Display plot of Thomas' City Unit design.

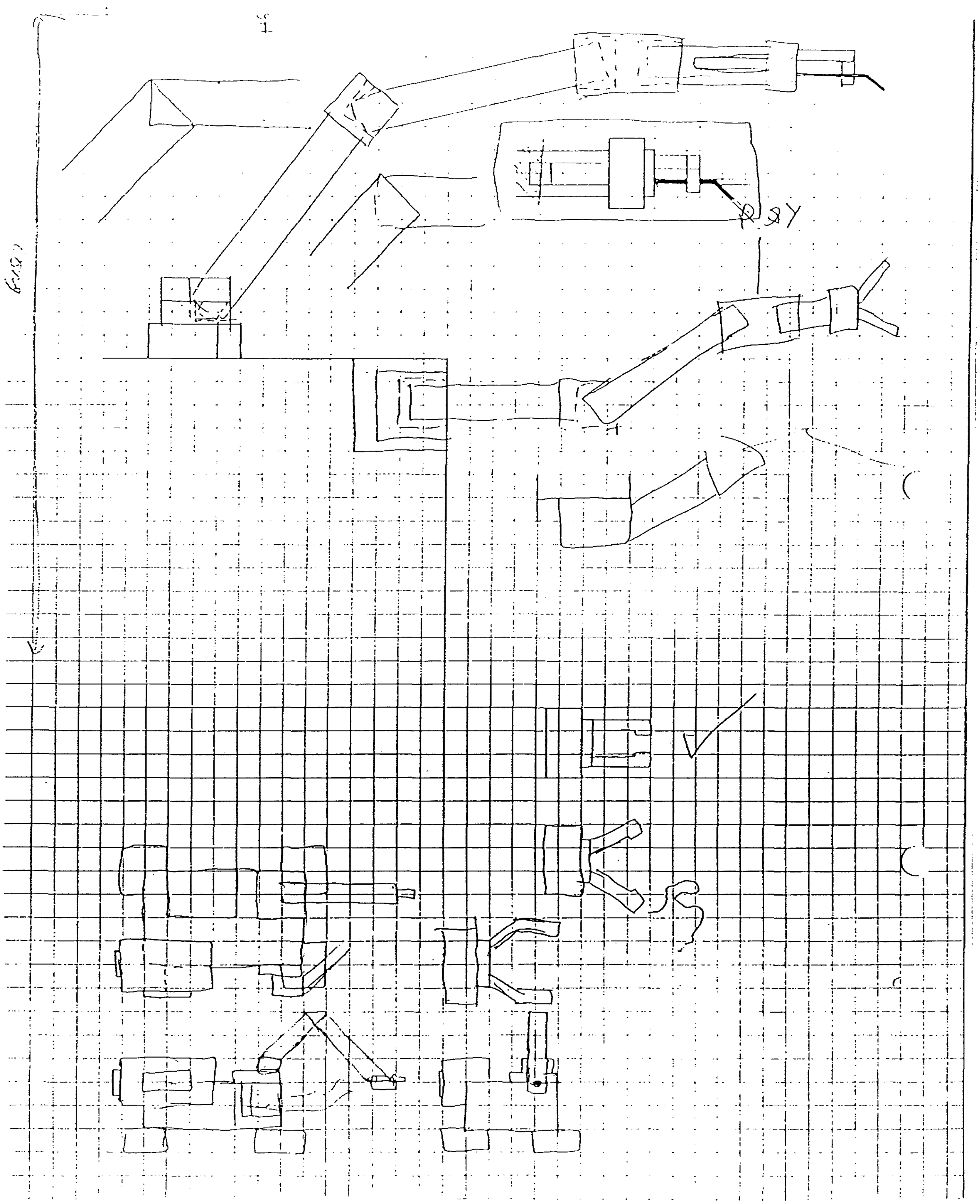


Fig. 37. Rowan Burrough's Robot 2 design. Preliminary design drawings.

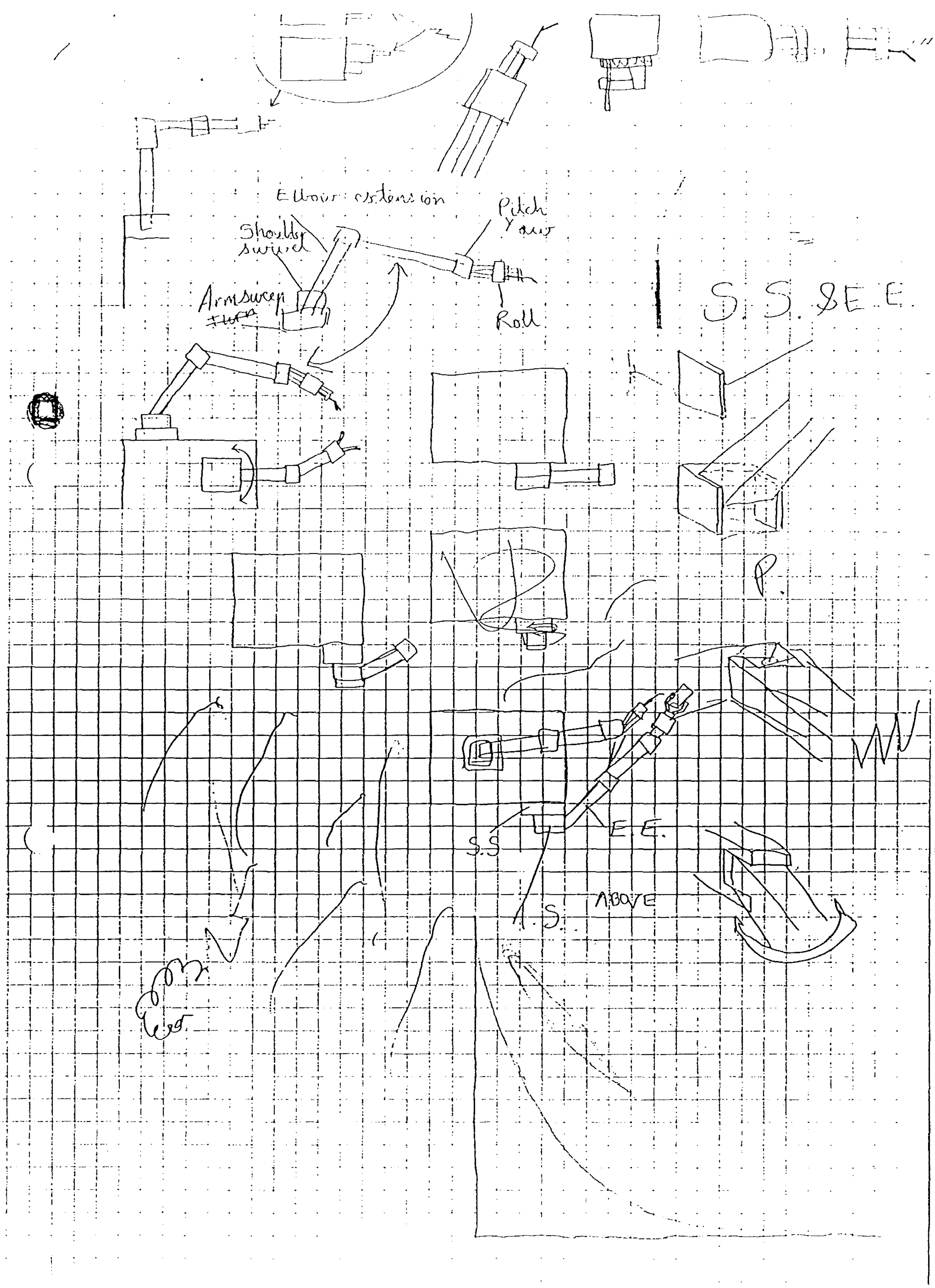


Fig. 38. Rowan Burrough's preliminary design drawings of Robot 2.

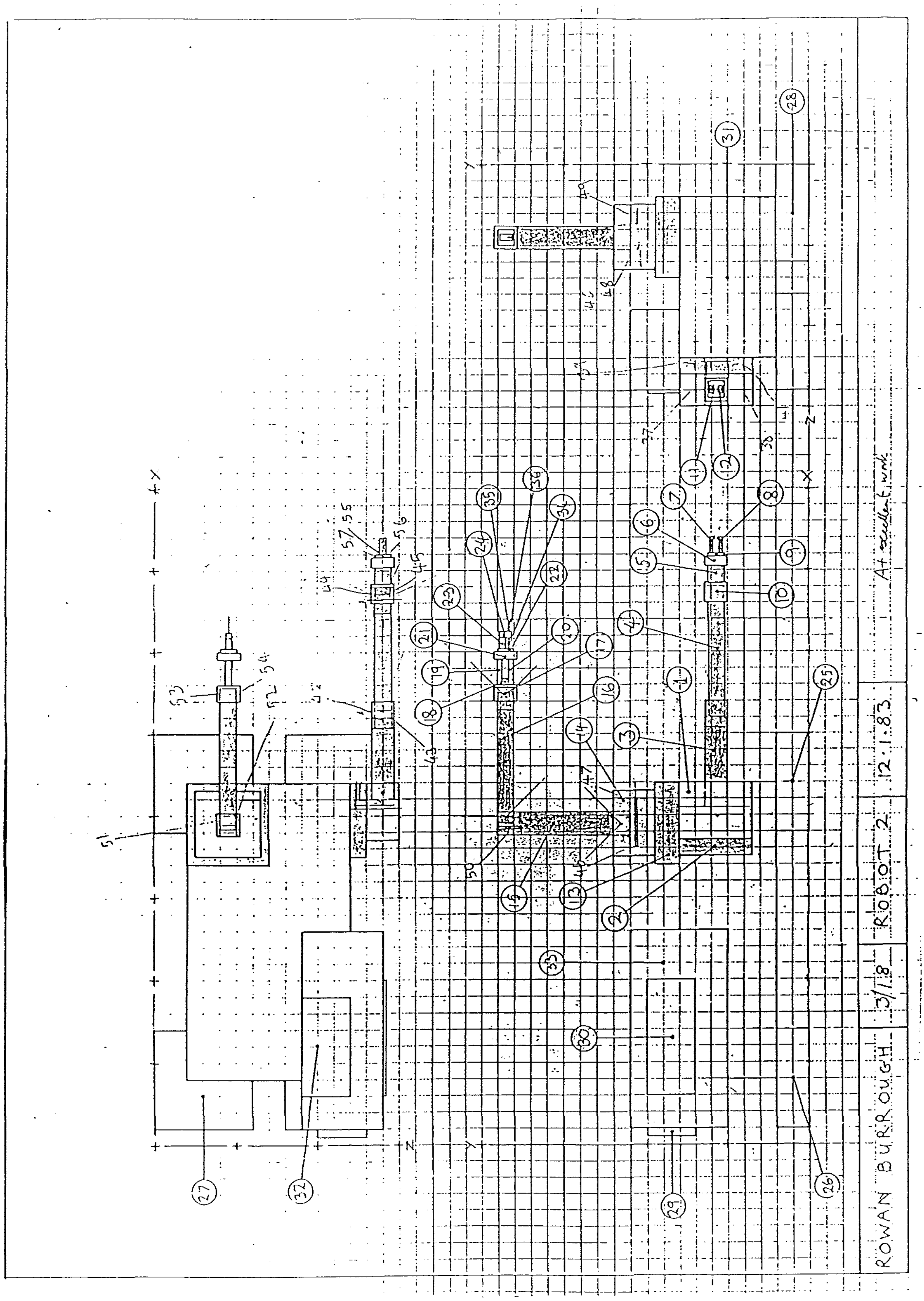


Fig. 39. Complete orthographic views of Rowan Burrough's Robot 2 design. Reduced from A3 square grid paper, parts of the original drawing are also coloured.

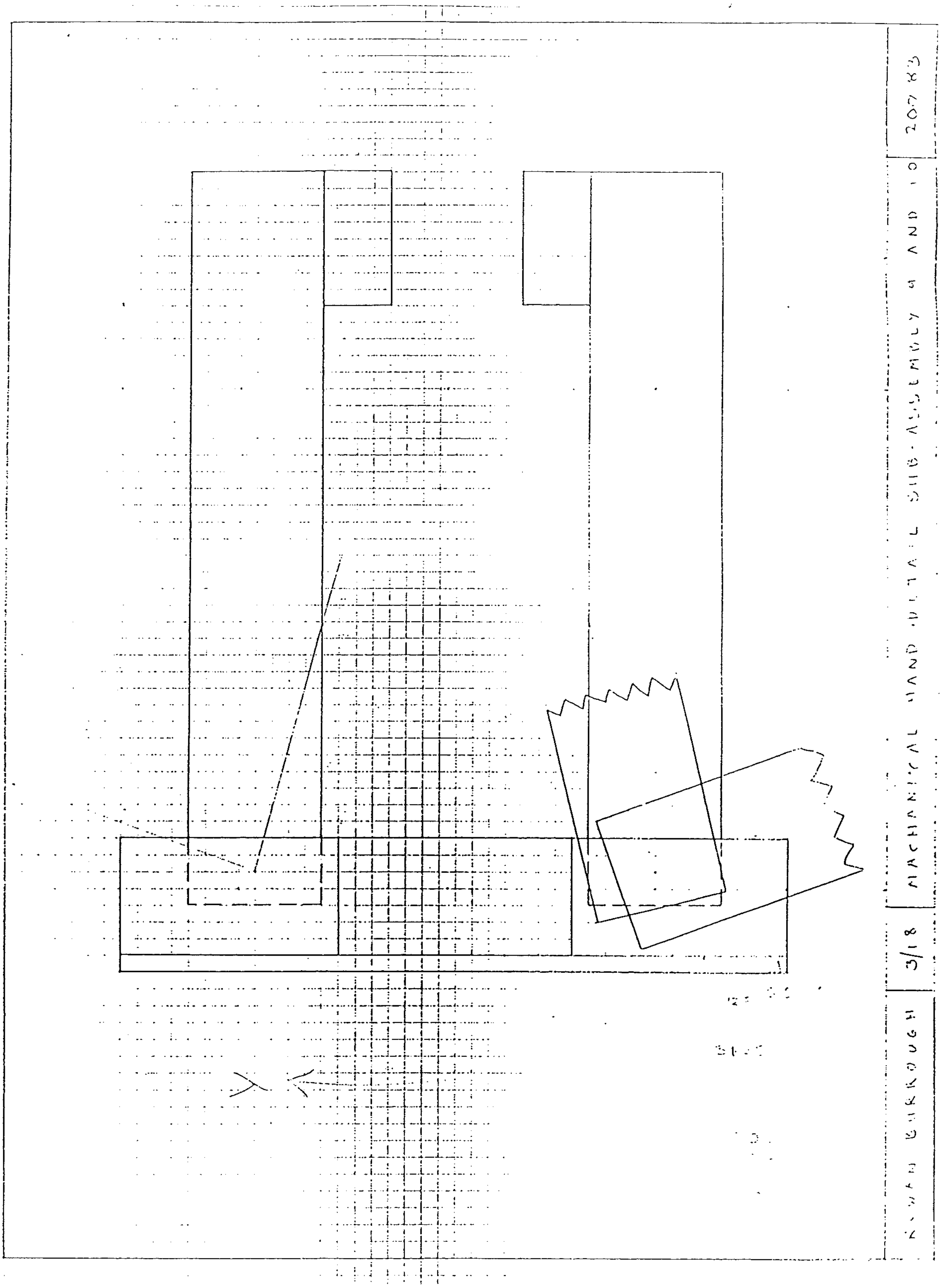


Fig. 40. Rowan Burrough's Robot 2, mechanical hand detail drawing of sub-assembly parts 9 and 10. Reduced from A3 size paper.

Your name and tutor group	Project title	Drg No
Kevan Burrough 3/18	Robot 2	1st July

CBDØ24

A

B

Unit	Width x	height y	depth z	coordinates of corner: Xcoord	Ycoord	Zcoord
1	3·~~4~~5	4·~~1~~5	2	18 5	3.5	13
2	4·~~2~~5	4 ~~2~~5	1	17.5	3·5	12
3	6	1·4	1·4	21	5	13·3
4	7	~~5~~1	~~7~~1	26	5·2	13·5
5	~~8~~1	~~8~~1	~~7~~1	34 2	5·2	13·5
6	0·6	1 4	1·4	35 2	5	13·3
7	1	0·2	0·4	36	5 9	13·8
8	1	0·2	0·4	36	5 3	13·8
9	0·2	1	1	35·8	5·2	13·5
10	1·2	1·4	1·4	33	5	13·3
11	0·2	0·1	0·4	36·8	5·8	13·8
12	0·2	0·1	0·4	36·8	5·5	13·8
13	5	1·5	5	17	~~6~~8	2
14	4	2·5	4	17·5	9~~7~~·5	2·5
15	1·4	8	1·4	18·8	11	3·8
16	7·5	1	1	19·5	18	4
17	1	1·4	1·4	27	17·8	3·8
18	0·4	0·4	0·4	28	18·3	4·3
19	1·6	0·3	0·4	28	18·7	4·3
20	1·6	0·3	0·4	28	18	4·3

Notes:

Computer aided design Cuboid data

Fig. 41. Robot 2 Data sheet 1. Note cuboids 1–12 are referenced as being stored in datafile CBD024.

Your name and tutor group	Project title	Drg No
ROWAN BURROUGH 1/5	ROBOT 2	......

Part	Width X	Height Y	Depth Z	Coordinates of corner Xcoord	Ycoord	Zcoord
21	0·4	1·4	1·4	29·5	17·8	3·8
22	0·2	1	1	30	18	4
23	0·5	0·4	0·4	30·2	18·5	4·3
24	0·4	0·7	0·4	30·8	18·2	4·3
25	6	2	6	19	0	8
26	6	2	6	1	0	14
27	6	2	6	1	0	0
28	6	2	6	19	0	0
29	0·5	3	3	0·5	7	10
30	7	3	0·2	3	7	14
31	18	6	10	4	2	2
32	6	3	0·0	3	11	9
33	12	6	5	1	5	9
34	0·6	0·0	0·0	30·2	18·3	4·5
35	0·4	0·0	0·0	31·2	18·3	4·5
36						

CSD025 B

C

CSD026

B

Notes:

Computer aided design Cuboid data

Fig. 42. Robot 2 data sheet 2

[illegible] ASSY	Axis [illegible]	Neg (-) Angle	Pos (+) Angle
ASSY 1	X, Z	45°	90°
S. ASSY 1	X, Y	45°	45°
S. ASSY 2	X, Y	45°	90°
S. ASSY 3	X, Y	45°	45°
S. ASSY 4	Z, Y	360°	360°
ASSY 2	X, Y	15°	45°
S. ASSY 5	X, Z	5 ~~4~~ 5°	60°
S. ASSY 6	X, Y	20°	45°
S. ASSY 7	X, Y	65°	65°
S. ASSY 8	Z, Y	360°	360°
S. ASSY 9	X, Y	15°	70°
S. ASSY 10	X, Y	70°	15°

ASSY 1 = {N 13, 14, 5, 16, 17, 18, 19, 20, 21, 22, 23, 24, 34, 35, 36, 46, 47, 48, 49, 50 – 54}

S. ASSY 1 = {15 – 24, 34 – 36, 50 – 54}

S. ASSY 2 = {16 – 24, 34 – 36, 53, 54}

S. ASSY 3 = {17 – 24, 34 – 36, 53, 54}

S. ASSY 4 = {21 – 24, 34 – 36}

ASSY 2 = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 37 – 45, 55 – 57}

S. ASSY 5 {3 – 12, 42 – 45, 55 – 57}

S. ASSY 6 {4 – 12, 44, 45, 55 – 57}

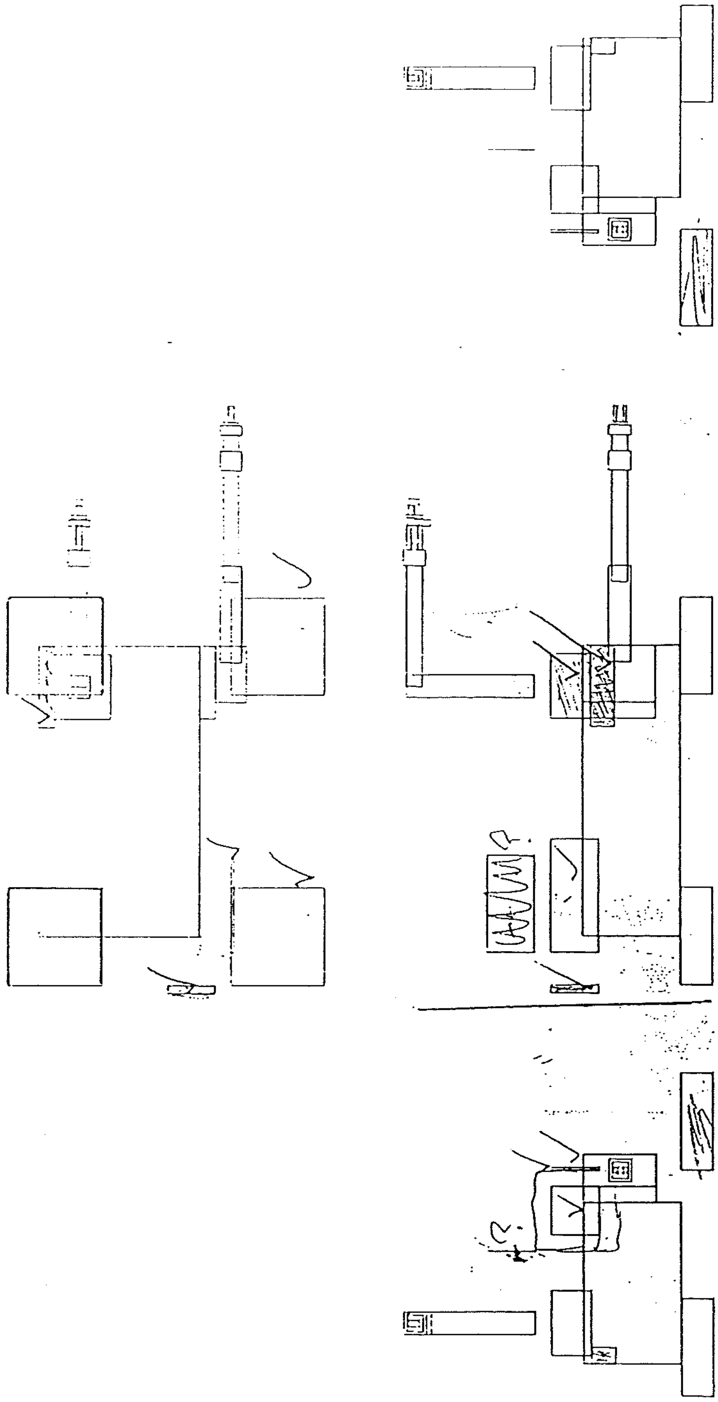
No PARTS 7 S. ASSY 7 {6 – 12, 55 – 57}

S. ASSY 8 {6 – 12}

S. ASSY 9 {7, 11}

S. ASSY 10 {8, 12}

Fig. 43. Robot 2 data sheet 3. Information about sub-assemblies.



15.5

5, 3, ? | ~~15~~ 3.5, 11.5 ?

Fig. 44. Robot 2 orthographic 4-view used to detect errors in the data.

```
**** STOP
OK, SLIST CBD024
CBD024
Robot 2 part A
Rowan Burrough
Creighton School
3/18
1st July 1983
12
   3.5        4.5        2.         18.5       3.5        13.
   4.5        4.5        1.         17.5       3.5        12.
   6.         1.4        1.4        21.        5.         13.3
   7.         1.         1.         26.        5.2        13.5
   1.         1.         1.         34.2       5.2        13.5
   0.6        1.4        1.4        35.2       5.         13.3
   1.         0.2        0.4        36.        5.9        13.8
   1.         0.2        0.4        36.        5.3        13.8
   0.2        1.         1.         35.8       5.2        13.5
   1.2        1.4        1.4        33.        5.         13.3
   0.2        0.1        0.4        36.8       5.8        13.8
   0.2        0.1        0.4        36.8       5.5        13.8
EOF
OK,
   0.2        0.1        0.4        36.8       5.5        13.8
EOF
OK, SLIST CBD025
CBD024
Robot 2 part B
Rowan Burrough
Creighton School
3/18
1st July 1983
12
   5.         1.5        1. c/1/5   17.        6 c/6/8    2.
   4.         2.5        4.         17.5       7.5 c/7.5/9.5  2.5
   1.4        8.         1.4        18.8       11.        3.8
   7.5        1.         1.         19.5       18.        4.
   1.         1.4        1.4        27.        17.8       3.8
   0.4        0.4        0.4        28.        18.3       4.3
   1.6        0.3        0.4        28.        18.7       4.3
   1.6        0.3        0.4        28.        18.        4.3
   0.4        1.4        1.4        29.5       17.5       3.8   typing error
   0.2        1.         1.         30.        18.        4.
   0.6        0.4        0.4        30.2       18.5       4.3
   0.4        0.7        0.4        30.8       18.2       4.3
   0.6        0.         0.         30.2       18.3       4.5
EOF0.4        0.         0.         31.2       18.3       4.5
OK,31.6 c/31.6/0.0  0.0      0.0       31.6       18.3       4.5
   1.6        0.3        0.4        28.        18.        4.3
   0.4        1.4        1.4        29.5       17.5       3.8
   0.2        1.         1.         30.        18.        4.
   0.6        0.4        0.4        30.2       18.5       4.3
   0.4        0.7        0.4        30.8       18.2       4.3
EOF
OK, SLIST CBD026
CBD026
Robot 2 part A  c/A/C
Rowan Burrough
Creighton School
3/18
1st July 1983
8
   6.         2.         6.         19.        0.         14  c/14/8
   6.         2.         6.         1.         0.         14  c/14/8
   6.         2.         6.         1.         0.         0.
   6.         2.         6.         19.        0.         0.
   0.5        3.         3.         0.5        7.         10.
   7.         3.         0.2        3.         7.         14.
   18.        6.         10.        4.         2.         2.
   6.         3 x/3/0    0 c/0/3    3.         11.        9.
EOF 12.       6.         5.         1.         5.         9.
OK,
```

Fig. 45. Robot 2 computer printouts of data files. Note the correction of errors, including the addition of cuboids.

CB0025

C3002-
Robot 2 part B
Rowan Burrough
Creighton School
3/1#
1st July 1985
14

13	5.	1.5	5.	17.	9.	2.
14	4.	2.5 c/2.5/1.	4.	17.5	9.5	2.5
15	1.4	5. c/8/6.5	1.4	18.8	11.	3.5
16	7.5	1.	1.	19.5	18.	4.
17	1. c/1/0.2	1.4	1.4	27.	17.8	3.9
17	0.4	0.4	0.4	25.	18.3	4.3
19	1.6	0.3	0.4	28.	18.7	4.3
20	1.5	0.3	0.4	28.	18.	4.3
21	0.4	1.4	1.4	29.5	17.8	3.8
22	0.2	1.	1.	30.	18.	4.
23	0.5	0.4	0.4	30.2	18.5	4.3
24	0.4	0.7	0.4	30.8	18.2	4.3
34	0.5	0. c/0./0.001	0.	30.2	18.3	4.5
35	0.4	0. c/0./0.001	0.	31.2	18.3	4.5
36 { EOF	0.	0.	0.	31.6	18.3	4.5
	0.	0.	0.	32.2	18	4.5
47	0.5	1.5	4.	21.	10.5	2.5
46 ~~48~~	0.5	1.5	4.	17.5	10.5	2.5
48	3.	1.5	1.3	18.	10.5	5.2
49	3.	1.5	1.3	18.	10.5	2.5
50	0.4	1.5	1.4	18.8	17.5	3.8
51	1.	1.5	0.2	19.2	17.5	3.8
52	1.	1.5	0.2	19.2	17.5	5.
53	0.8	1.4	0.2	27.	17.8	3.8
54	0.8	1.4	0.2	27.	17.8	5.

! XH2 Coords of a "strut" to be joined
6 part B. ("Part 36")
Thickness = 0.001

Fig. 46. Robot 2 part B data file printout correction of errors. Note the comment by the author refering to data to be used for LNE3D not for cuboids.

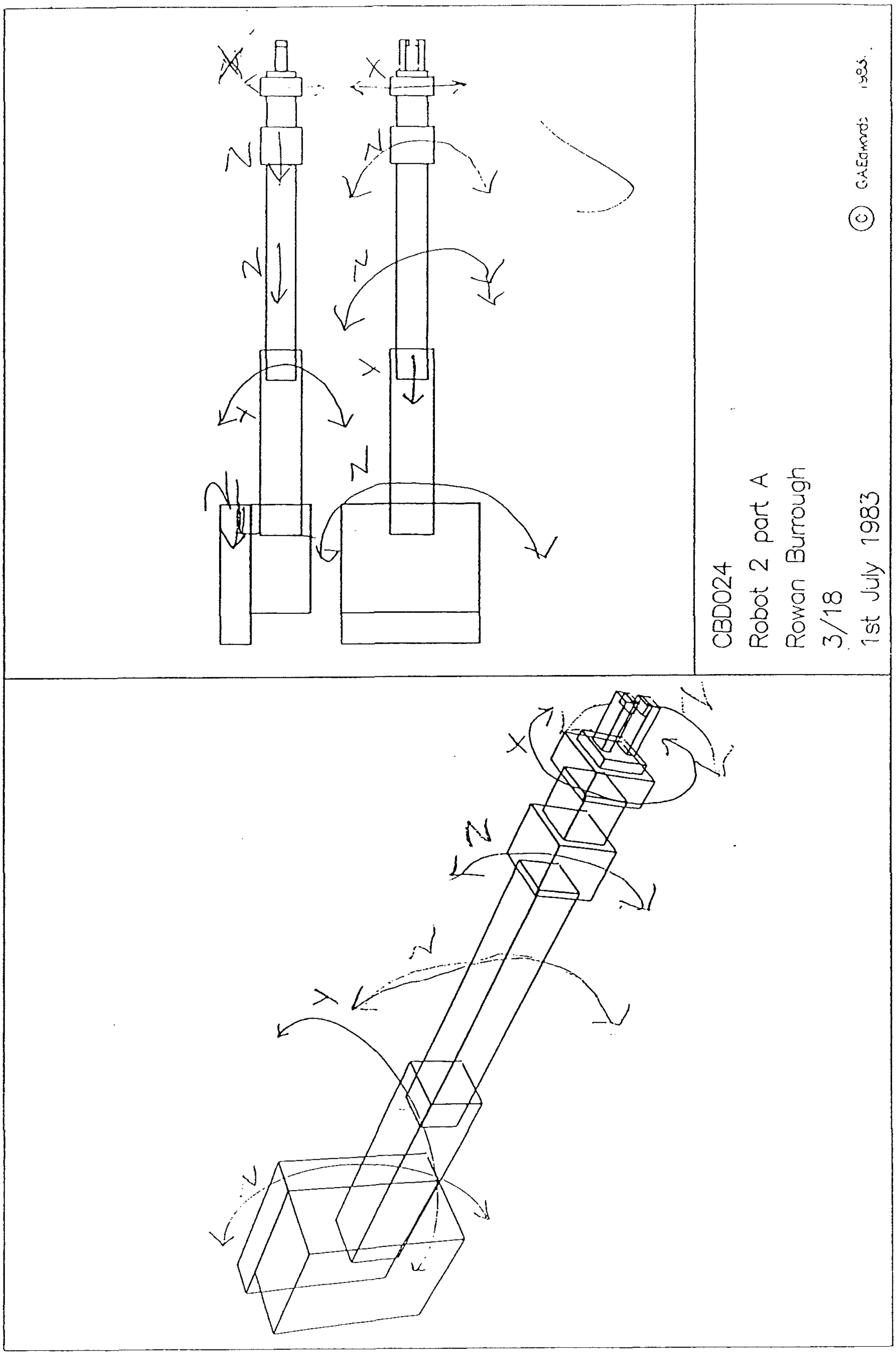


Fig. 47. Robot 2 part A. Plot used to label those component parts which are to be defined as sub-assemblies and for indicating rotational freedoms.

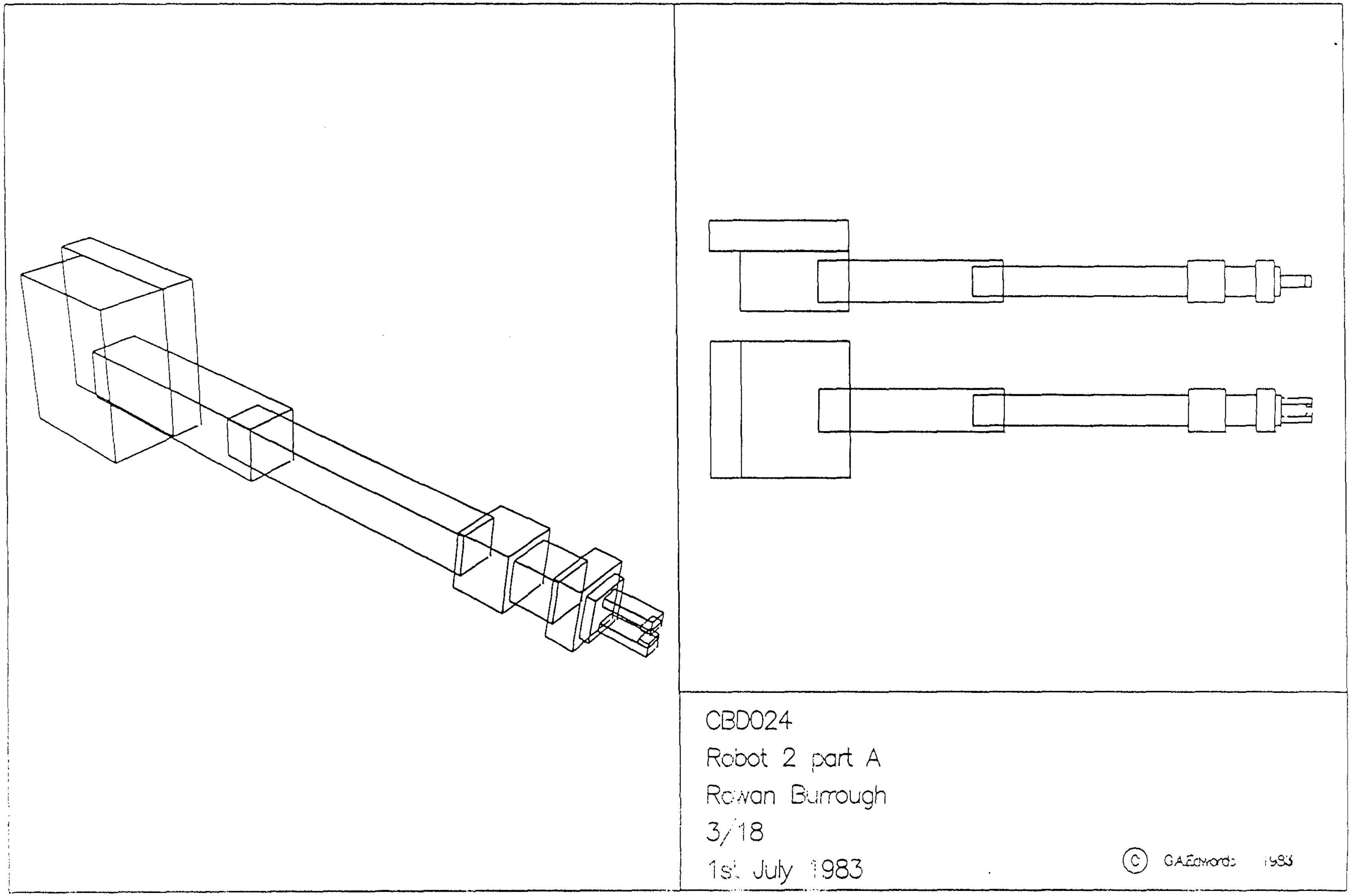


Fig. 48. Robot 2 part A. Check plot of the sub-assembly.

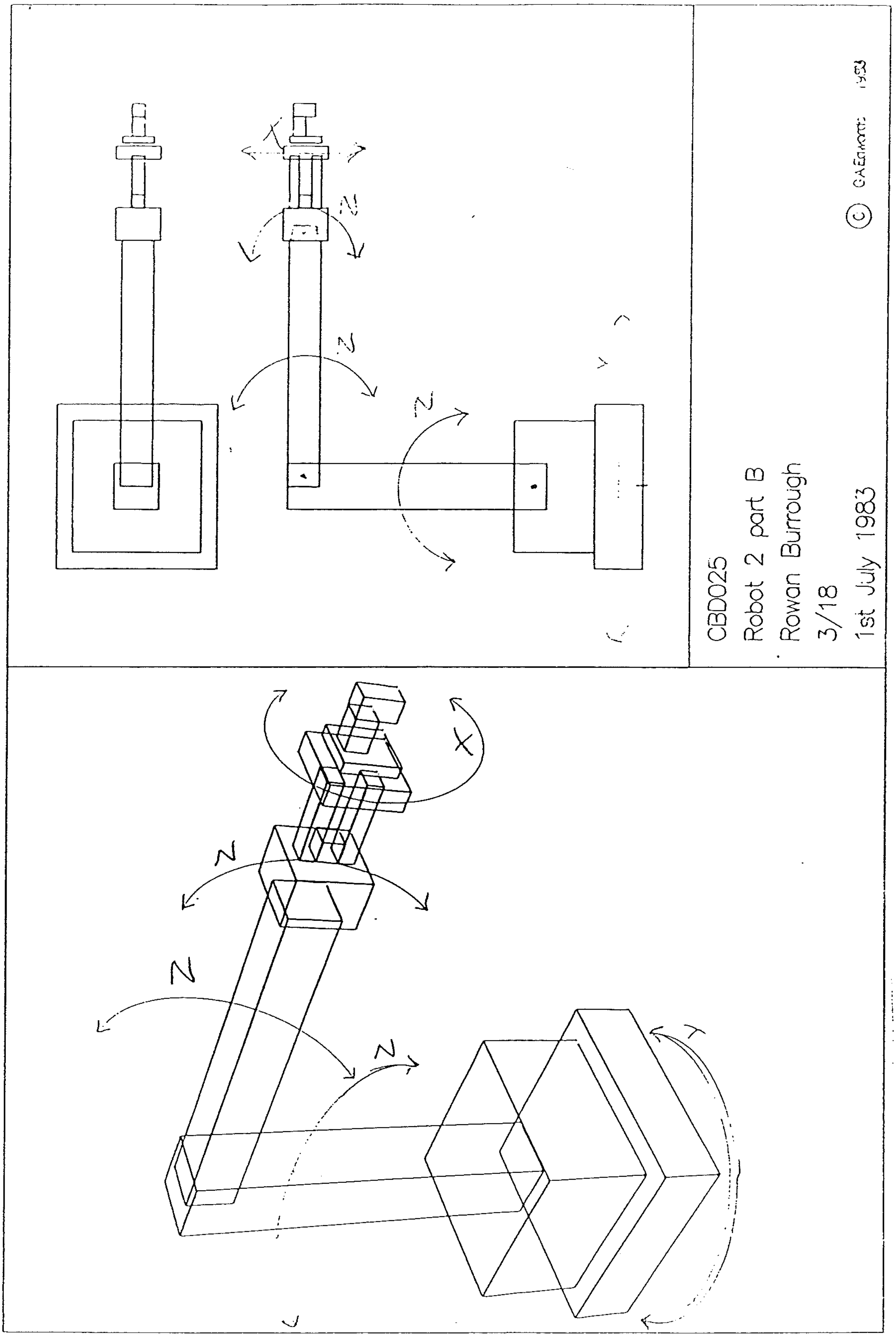
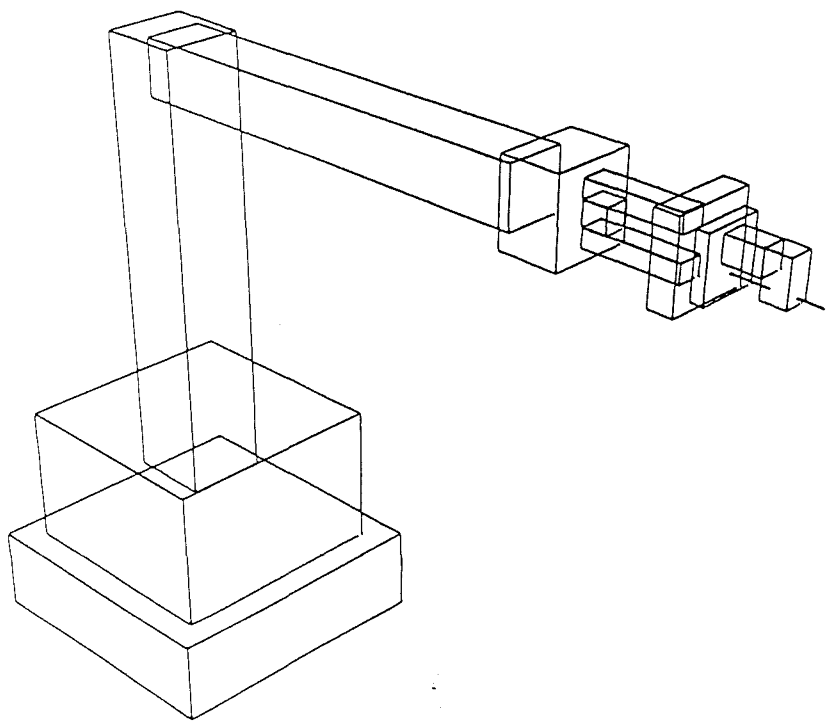
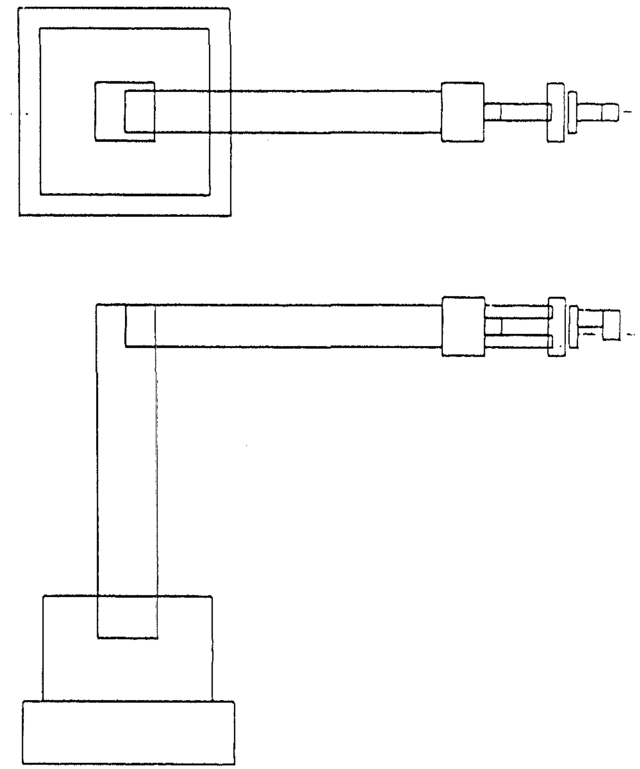


Fig. 49. Robot 2 part B. Plot used for determining rotational freedoms of component parts of the main assembly part B.

Fig. 50. Robot 2 part B check plot.





CBD025
Robot 2 part B
Rowan Burrough
3/18
1st July 1983

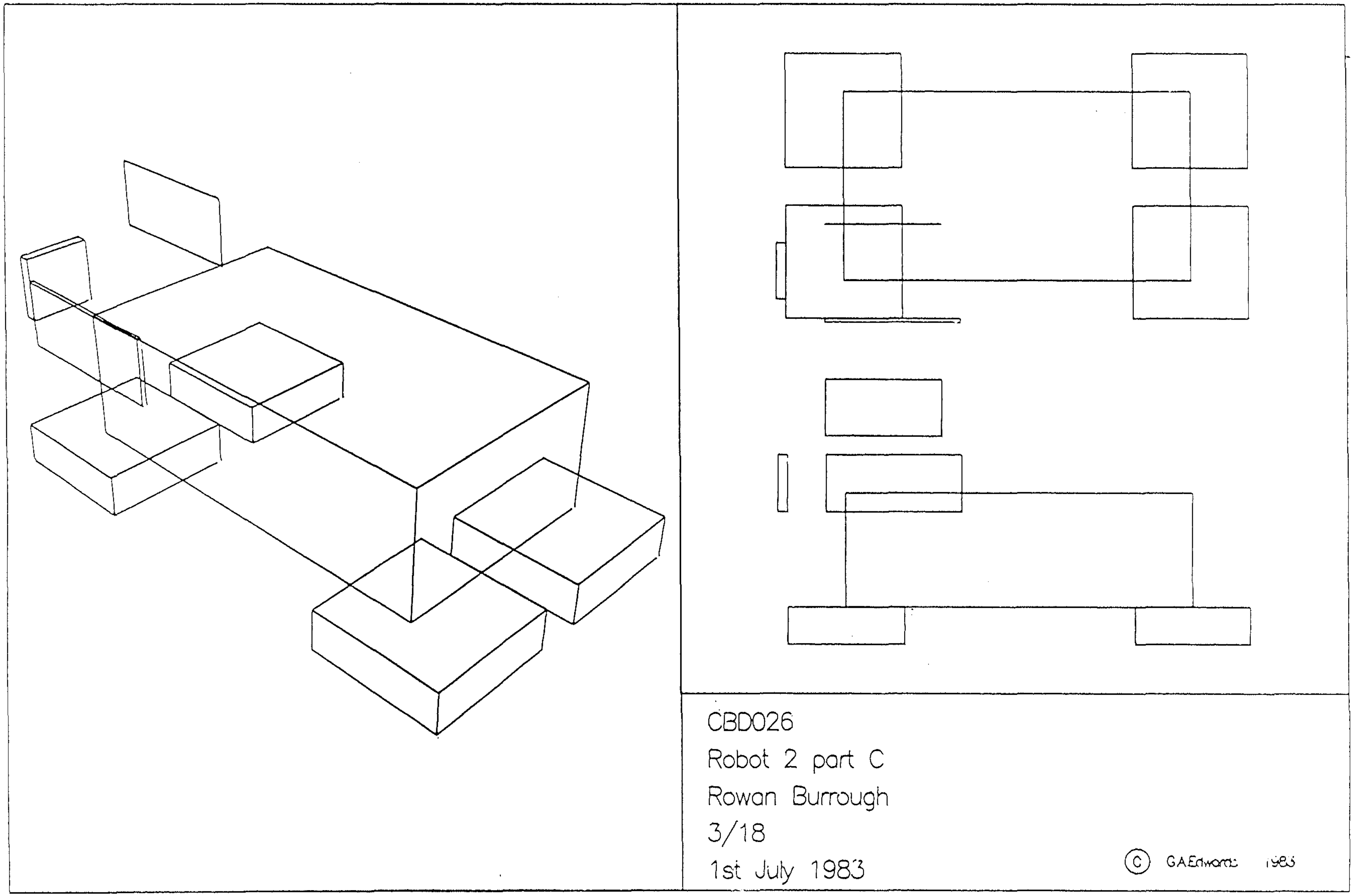


Fig. 51. Robot 2 part C. Check plot of main assembly

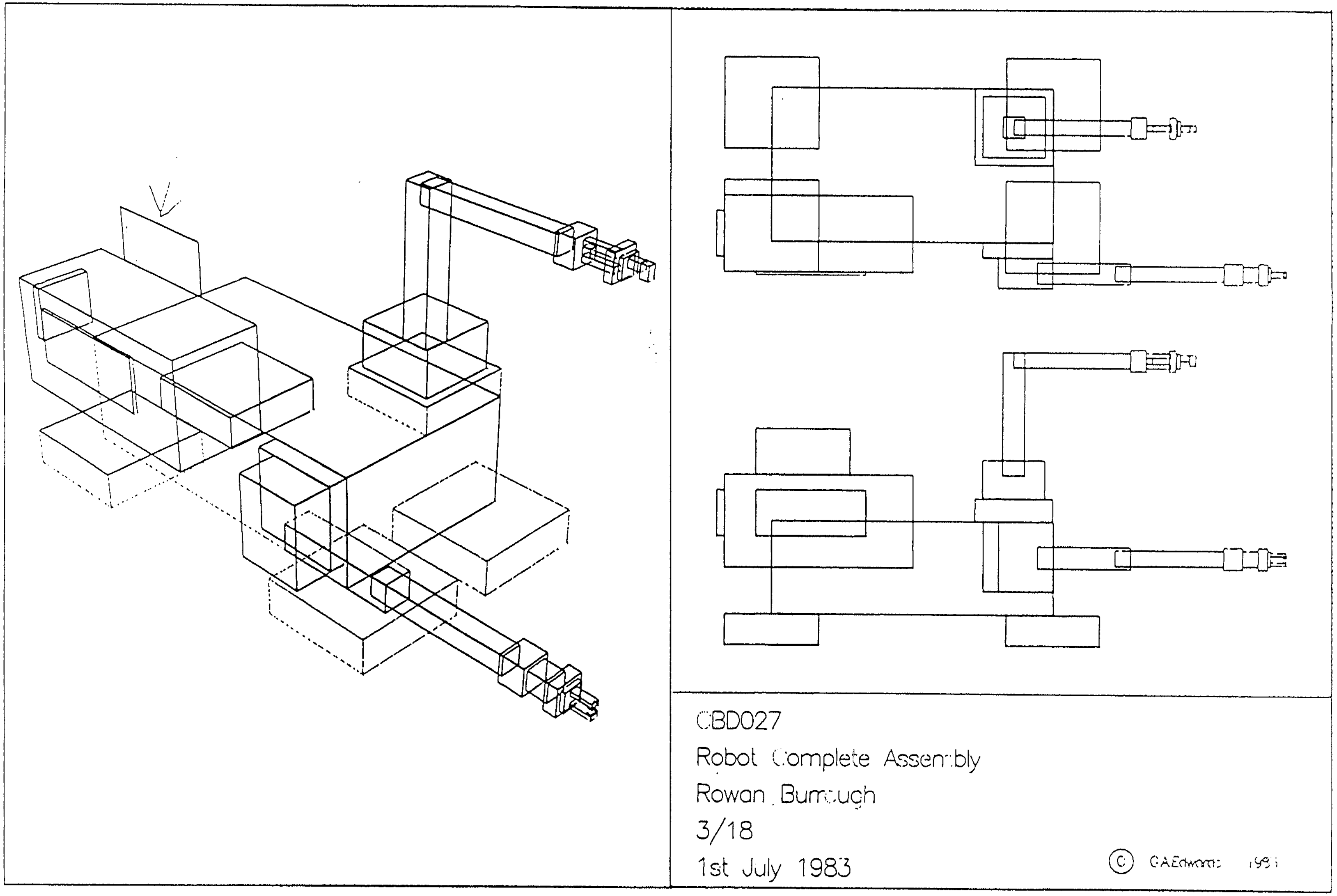


Fig. 52. Robot 2 complete assembly check plot. Note the error.

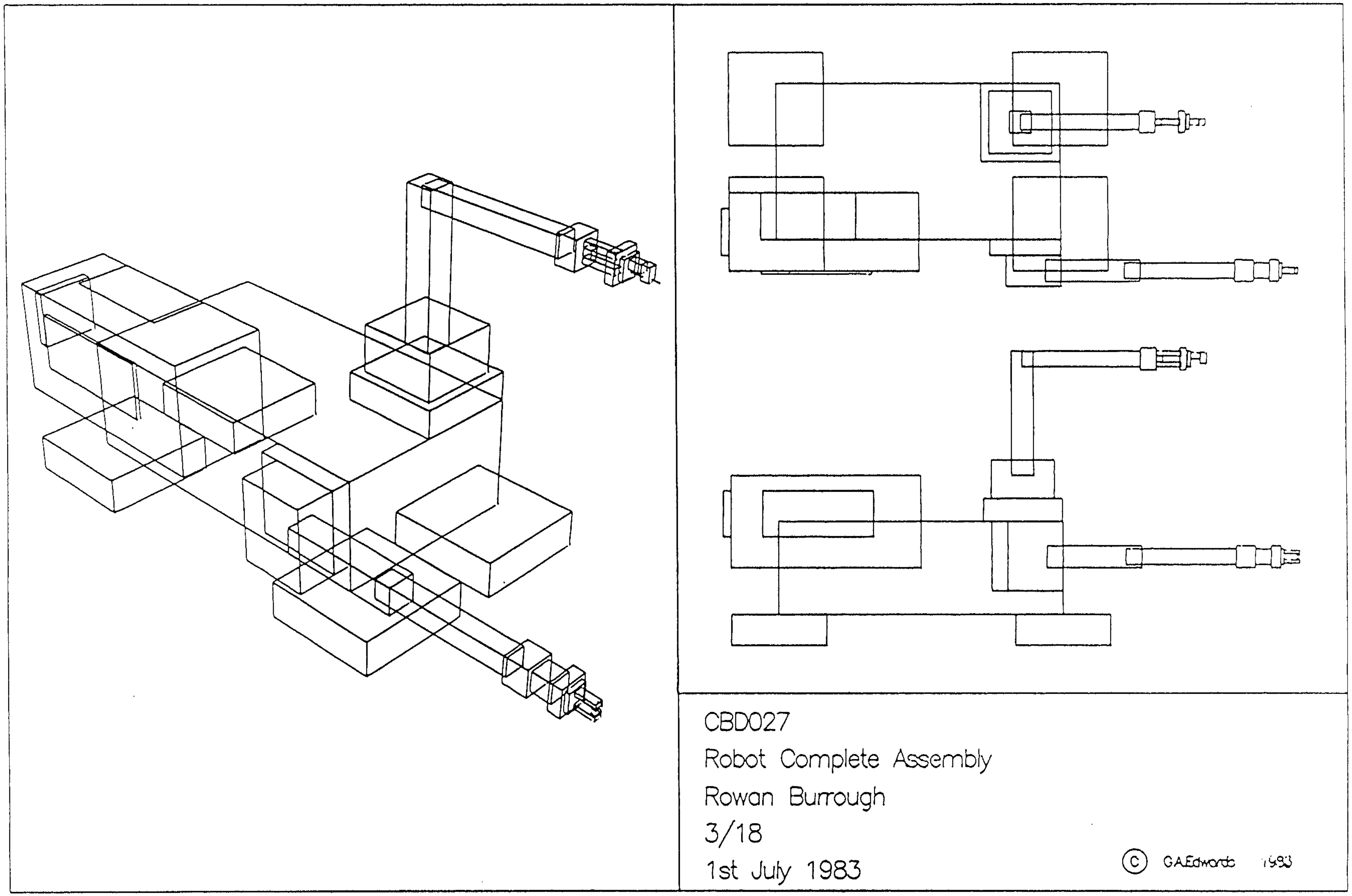


Fig. 53. Robot 2 complete assembly error-free check plot.

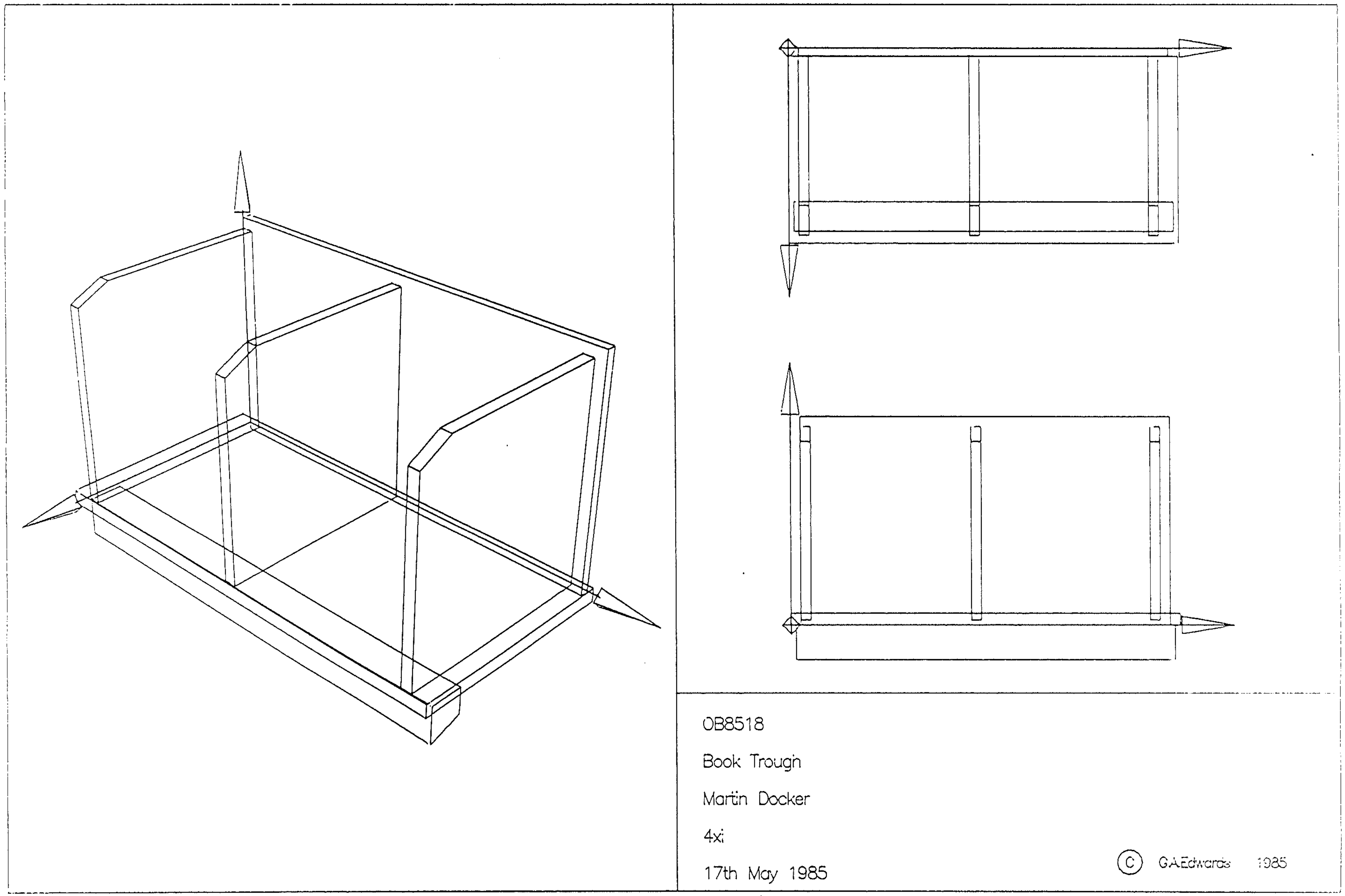
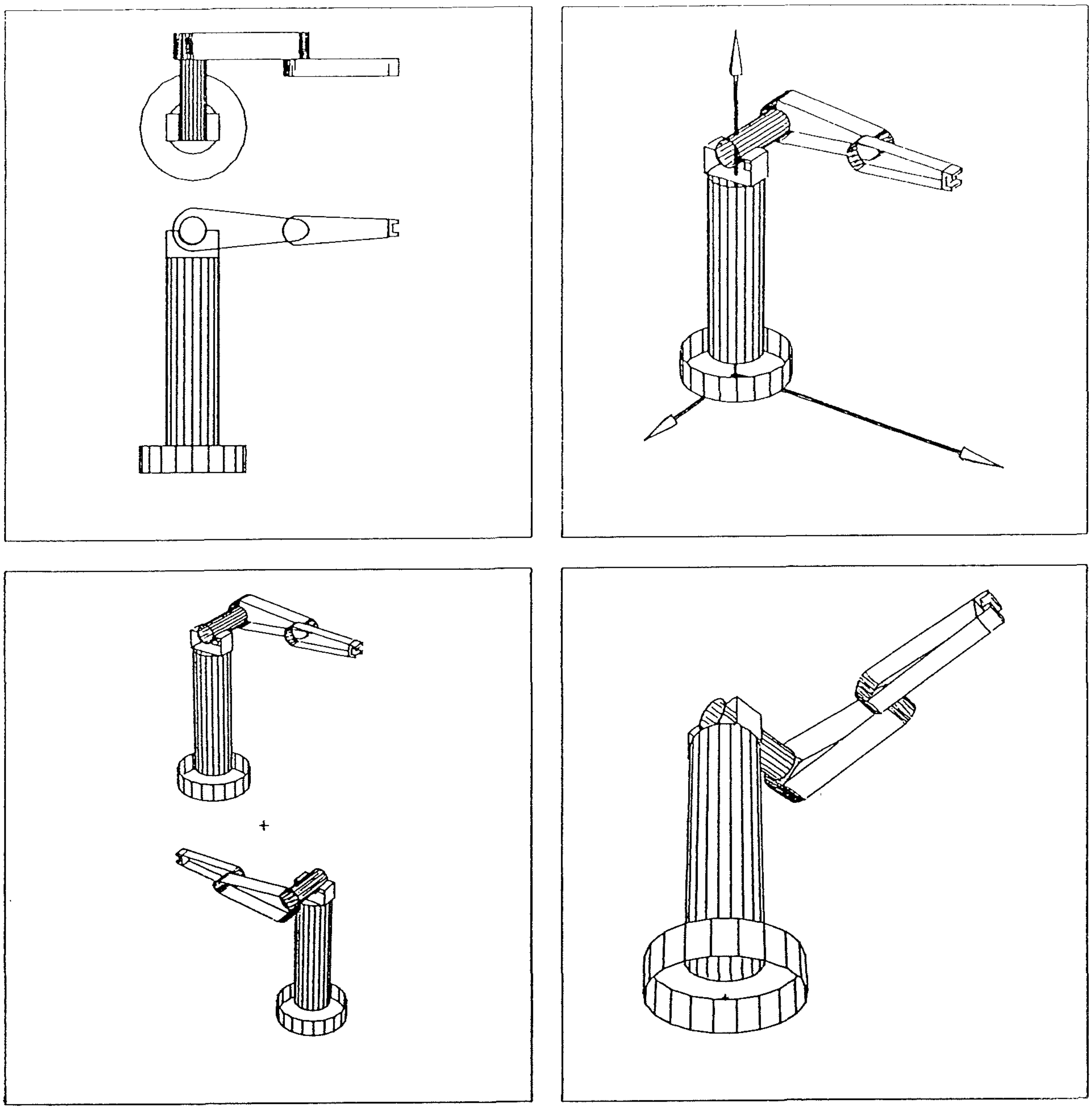


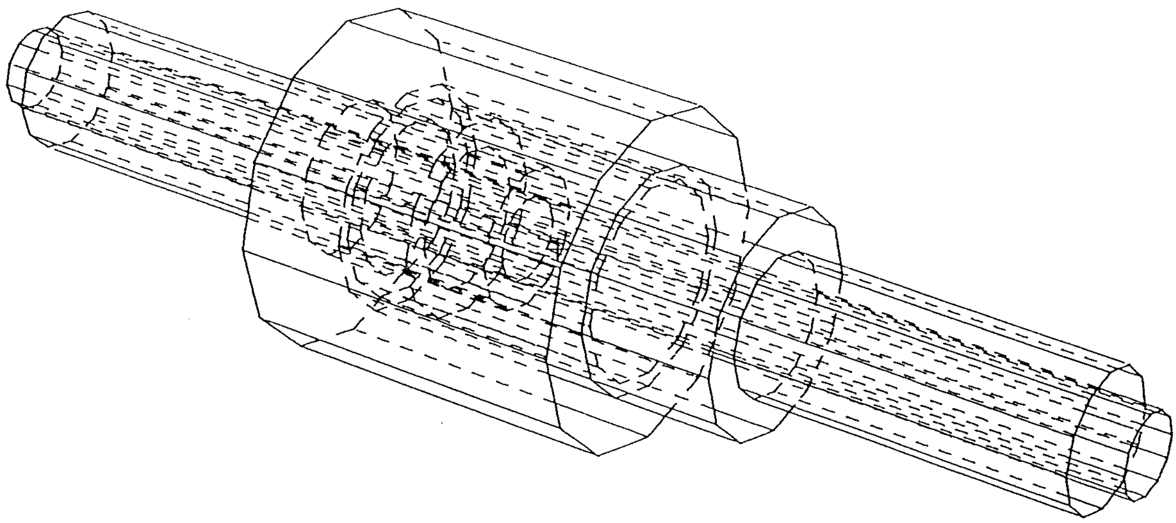
Fig. 54. Book Trough by Martin Docker. A CSE graphical communication project.



"ROBOT ASSEMBLY"

BY· ARARAT BAGHOOMIAN
BSc. 3 ELECTRONICS ENG.
(PROJECT WORK)

Fig. 55. Robot assembly by Arat Baghoomian a mature student at Middlesex Polytechnic who used the authors programs to prepare illustrations for his thesis.



"Hydra" by Clive Carter

Hidden Detail

The computer produced drawing above shows quite clearly that a sectional perspective view of the component would have been preferable.

Fig. 56. Hydra a component designed by Clive Carter for an A level design and technology project.

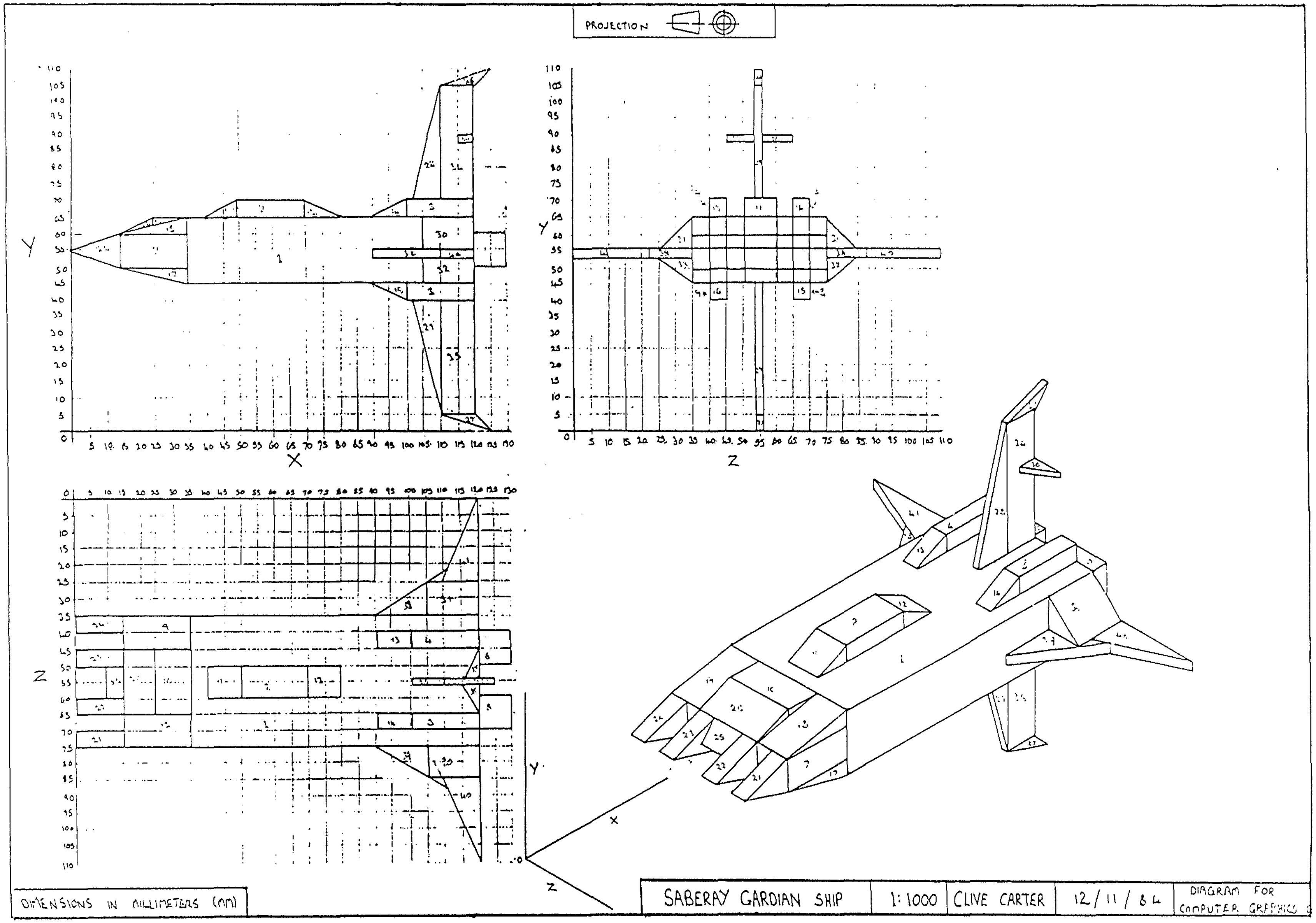


Fig. 57. Saberay Gardian (sic) Ship by Clive Carter orthographic and isometric pictorial view. The original was drawn on A3 plain paper.

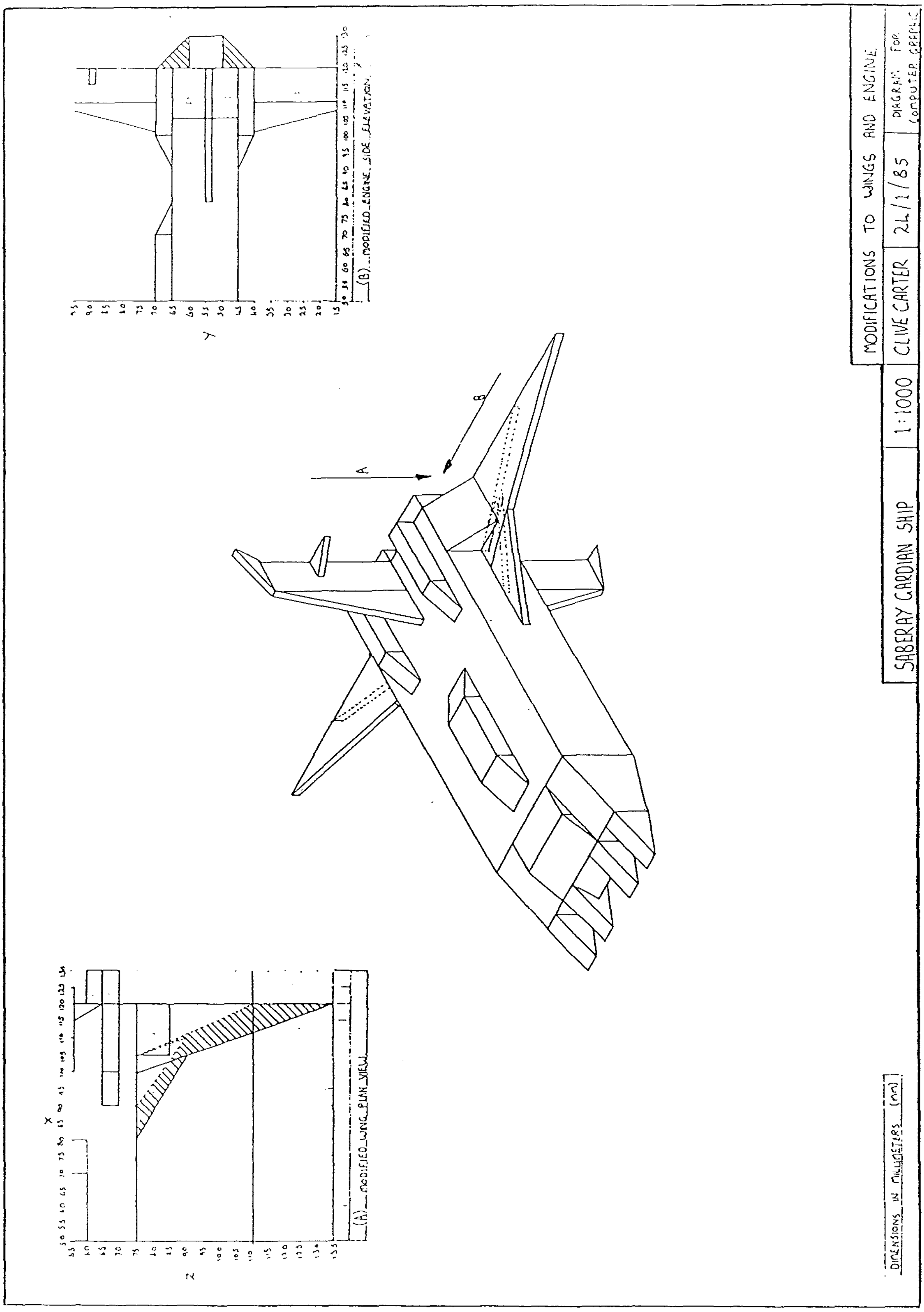
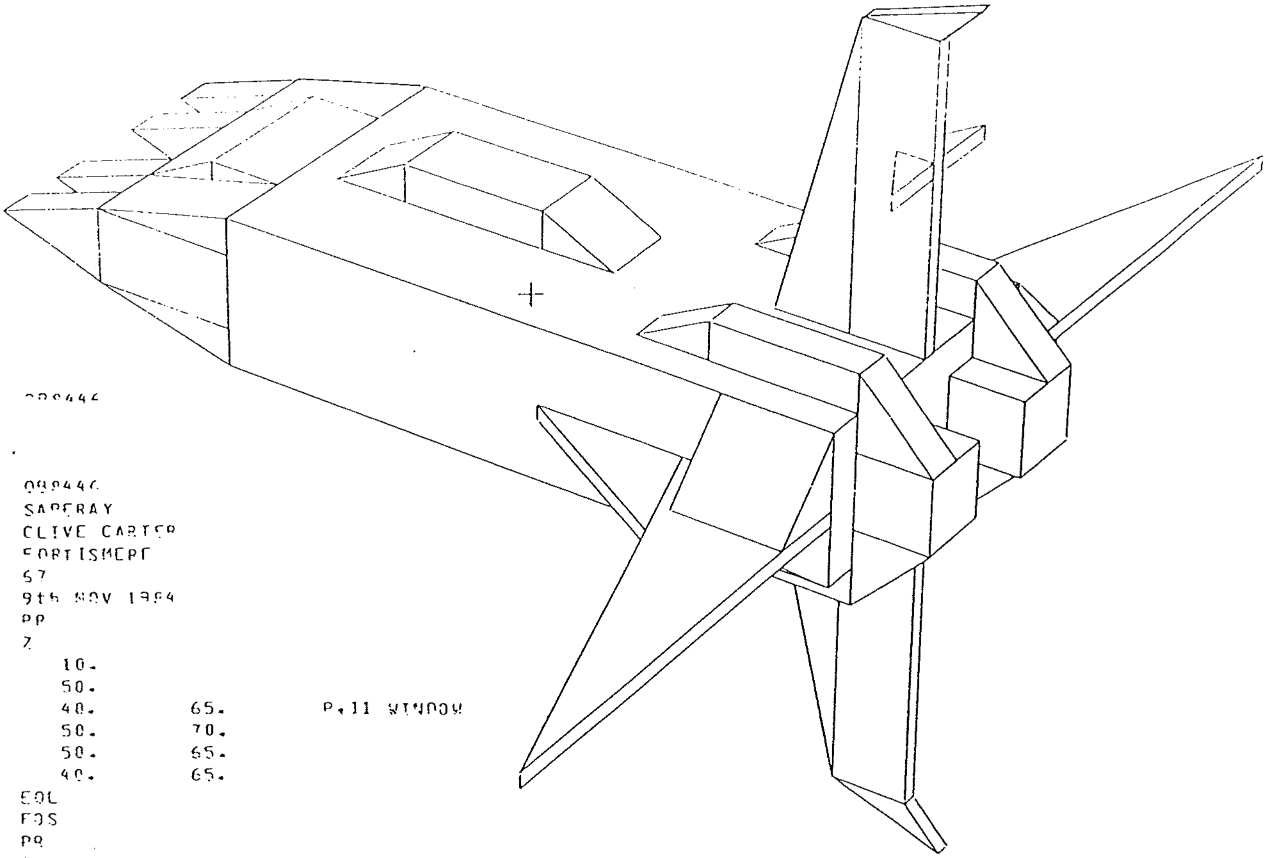


Fig. 58. Saberay, drawings showing modifications to the wings and engine. The original was drawn on A3 plain paper.



```
098446

098446
SABERAY
CLIVE CARTER
FORTISMERE
57
9th NOV 1984
PR
Z
    10.
    50.
    40.         65.         P,11 WINDOW
    50.         70.
    50.         65.
    40.         65.
EOL
EOS
PR
Z
    10.
    50.
    70.         65.         P,12 WINDOW
    70.         70.
    80.         65.
    70.         65.
EOL
EOS
PR
Z
    5.
    40.
    90.         65.         P,13 ENGINE
    100.        70.
    100.        65.
    90.         65.
EOL
EOS
PR
Z
    5.
    65.
    90.         65.         P,14 ENGINE
    100.        70.
    100.        65.
    90.         65.
EOL
EOS
PR
Z
    5.
    65.
    90.         45.         P,15 ENGINE
    100.        45.
    100.        40.
    90.         45.
```

Fig. 59. perspective plot of Saberay and computer printout of part of the OBJECTSYN1 data file. Note the addition of identification for each part.

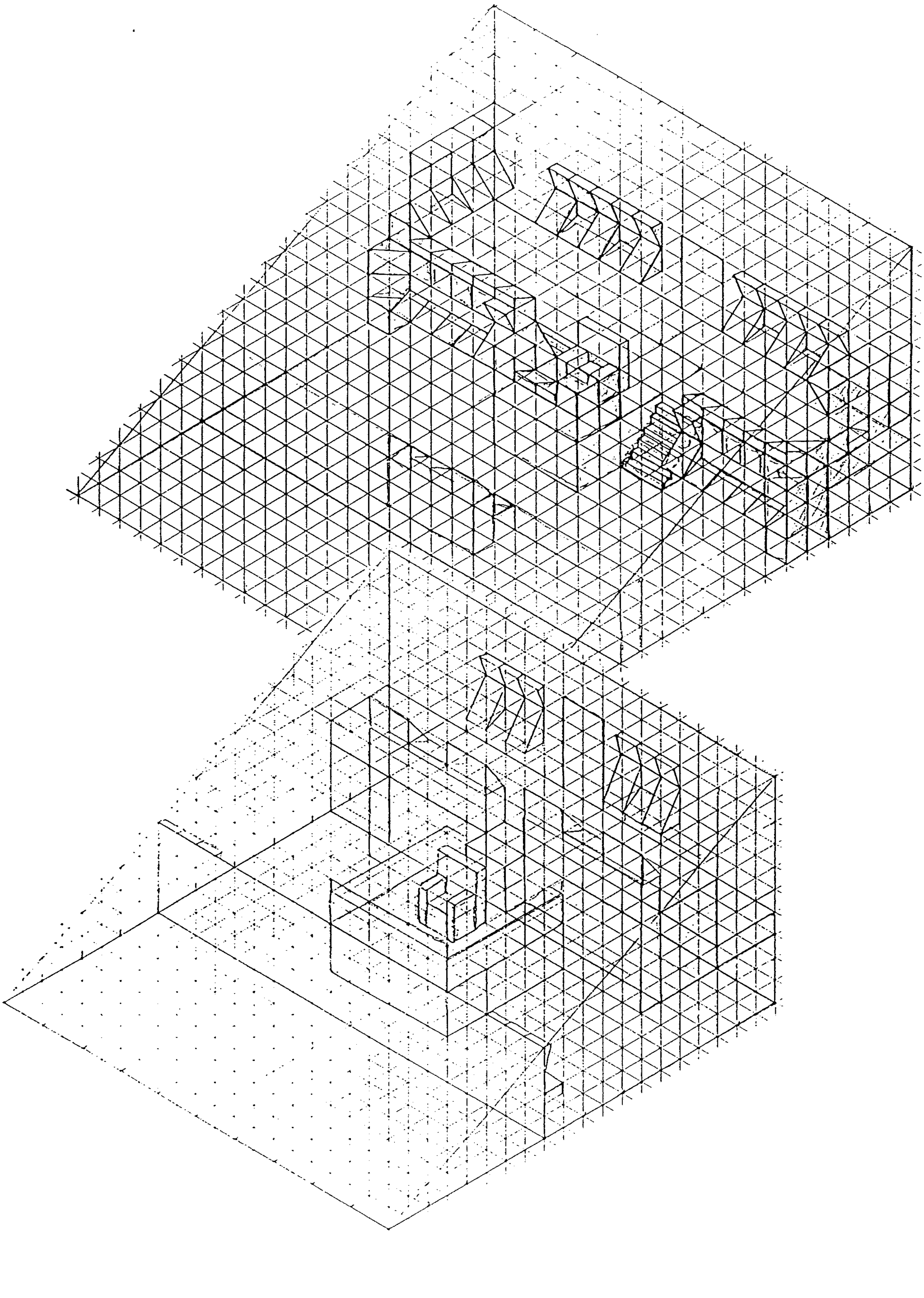


Fig. 60. Preliminary isometric drawings of the command centre for the Saberay spacecraft

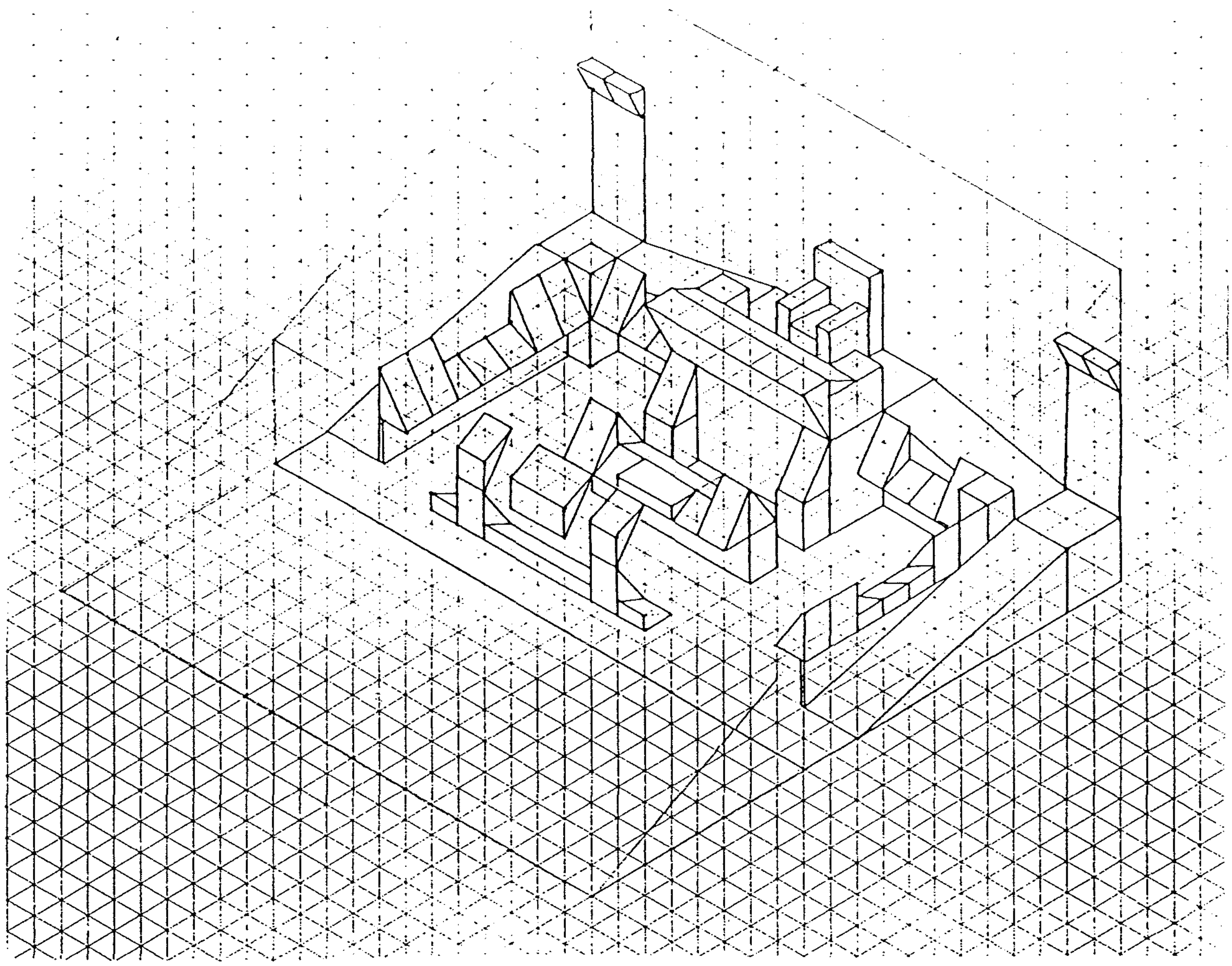


Fig. 61. Final design for the command centre of the Saberay spacecraft.

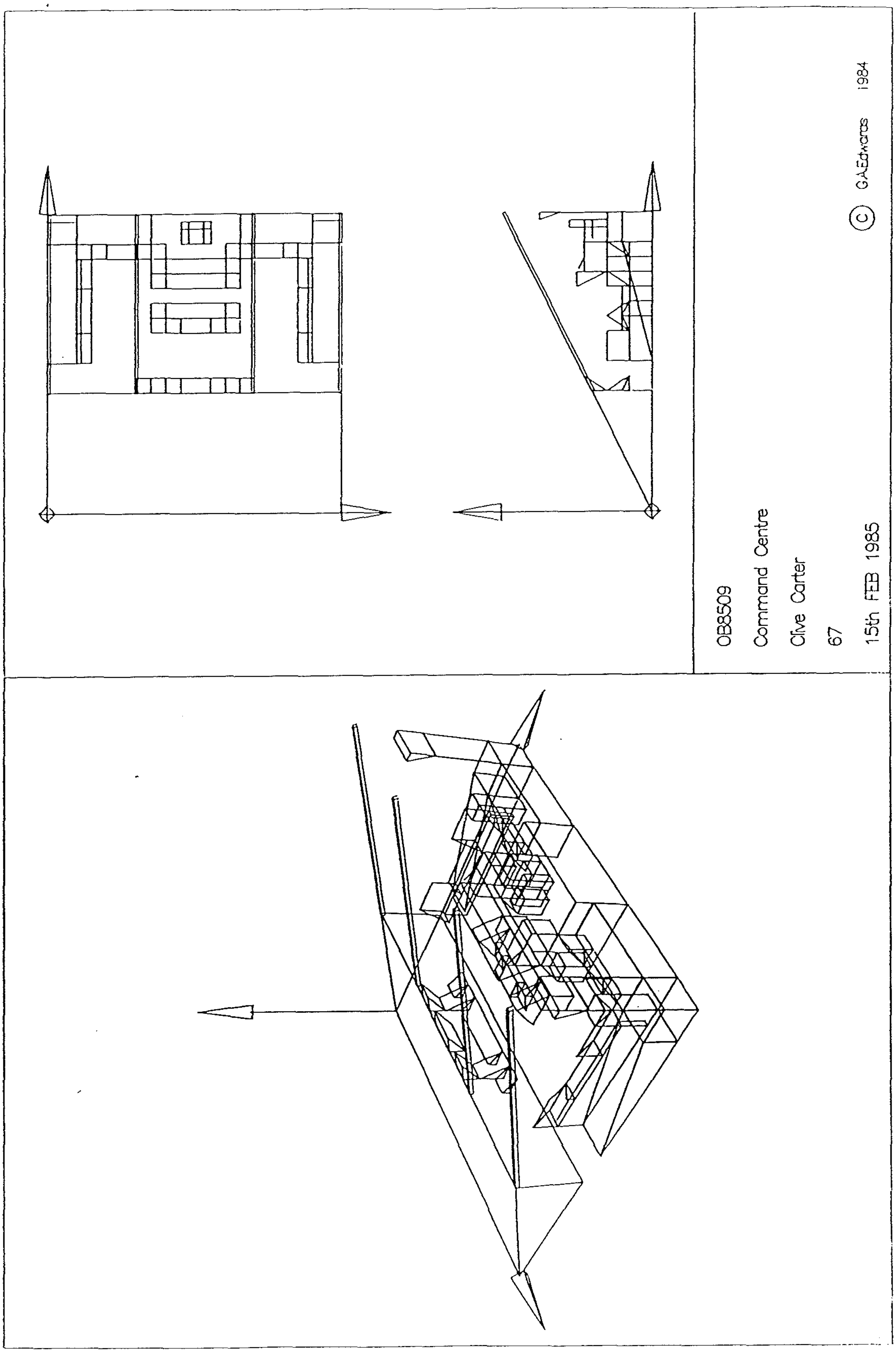


Fig 62. Check plot of the command centre for the Saberay spacecraft. Because of the amount of data it was not possible to generate hidden line perspective views of the Saberay complete with its command centre.

APPENDIX 4

OWN COMPUTER DRAWINGS AND SOURCE DATA

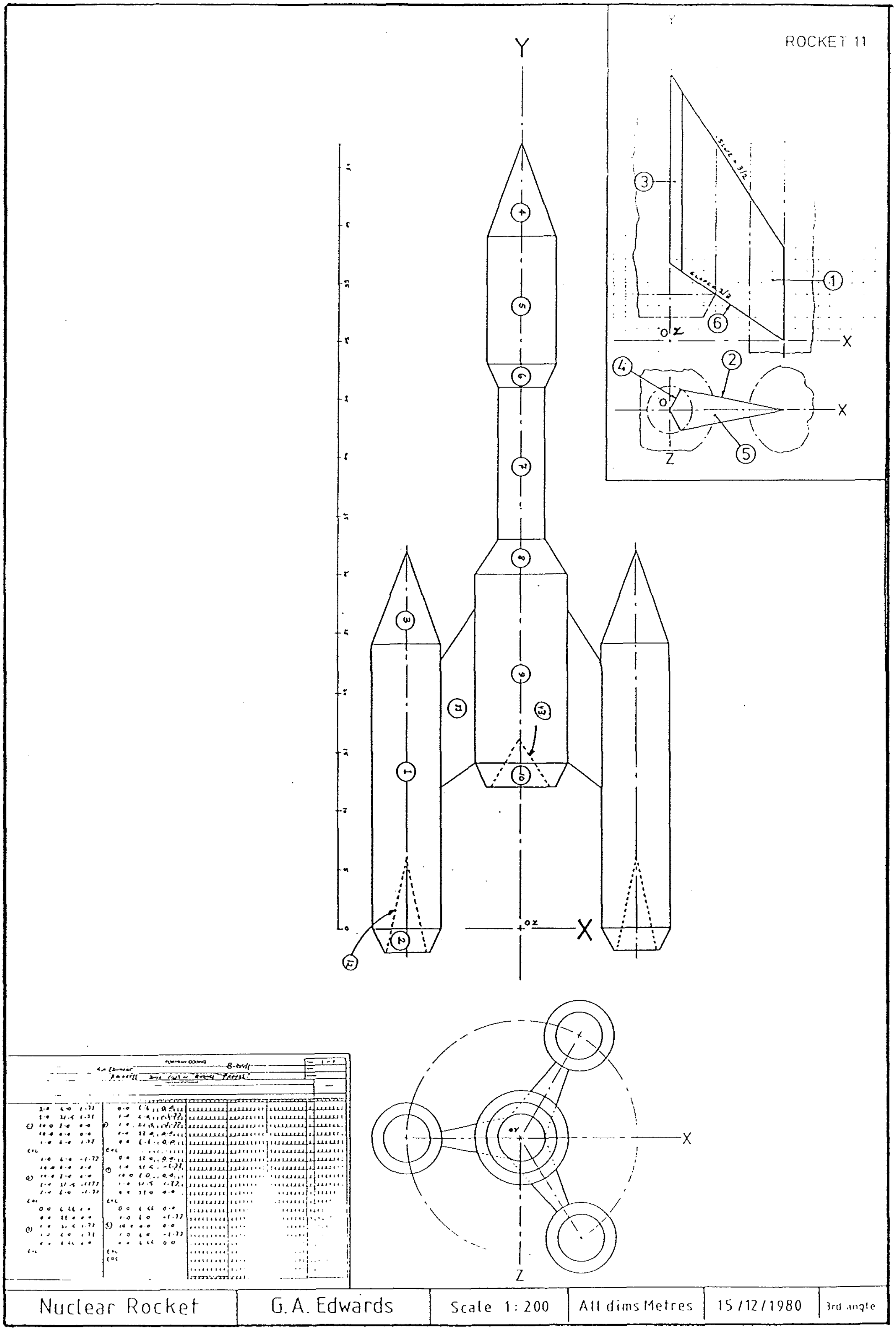


Fig. 1. Nuclear Rocket based on a design by Azam Bakshov a 2nd year pupil at Creighton School 1978. Drawn by the author for generation by the computer. Original drawing is A2 size square grid paper.

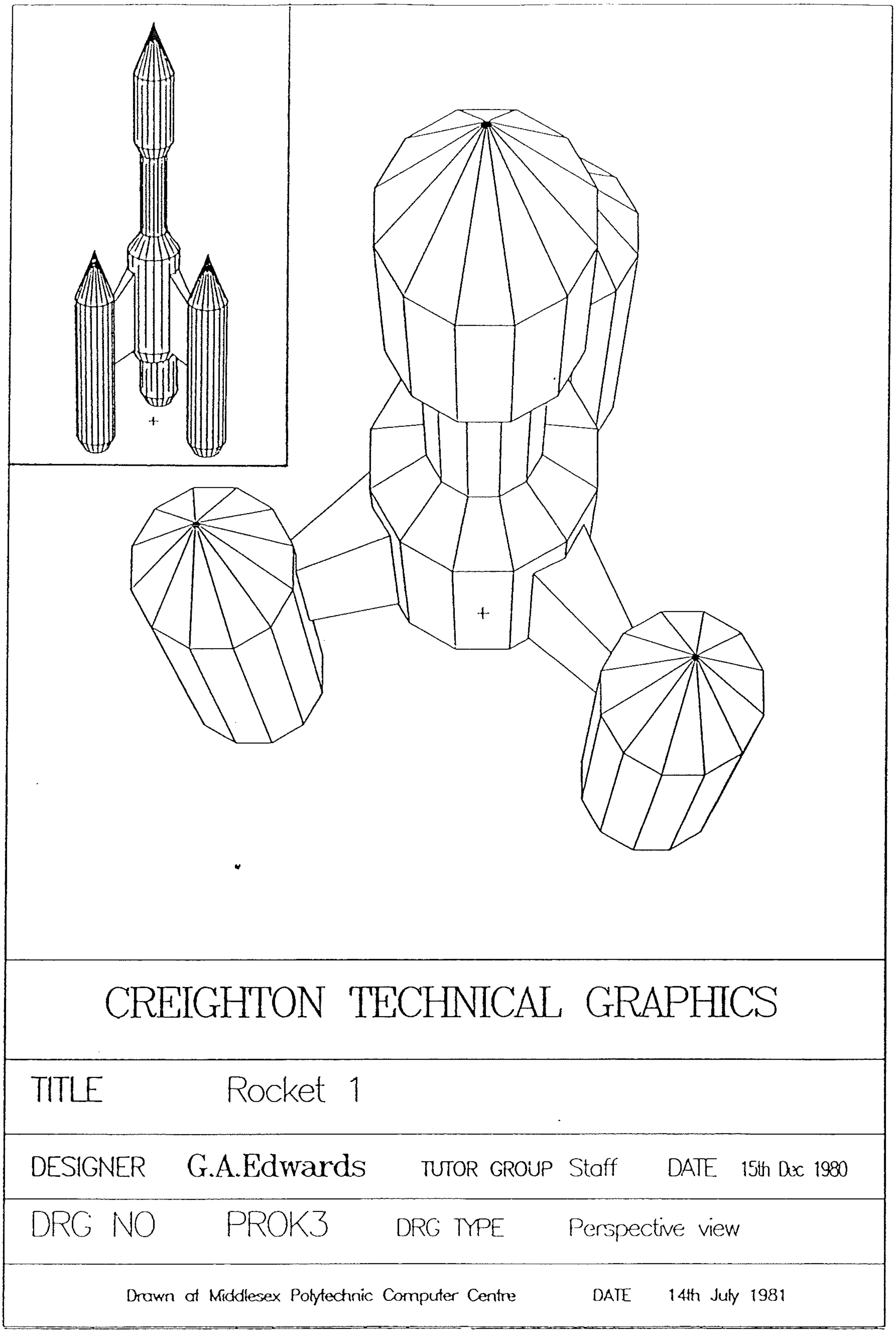


Fig. 2. Nuclear Rocket an unusual perspective view of the rocket and inset a more conventional view.

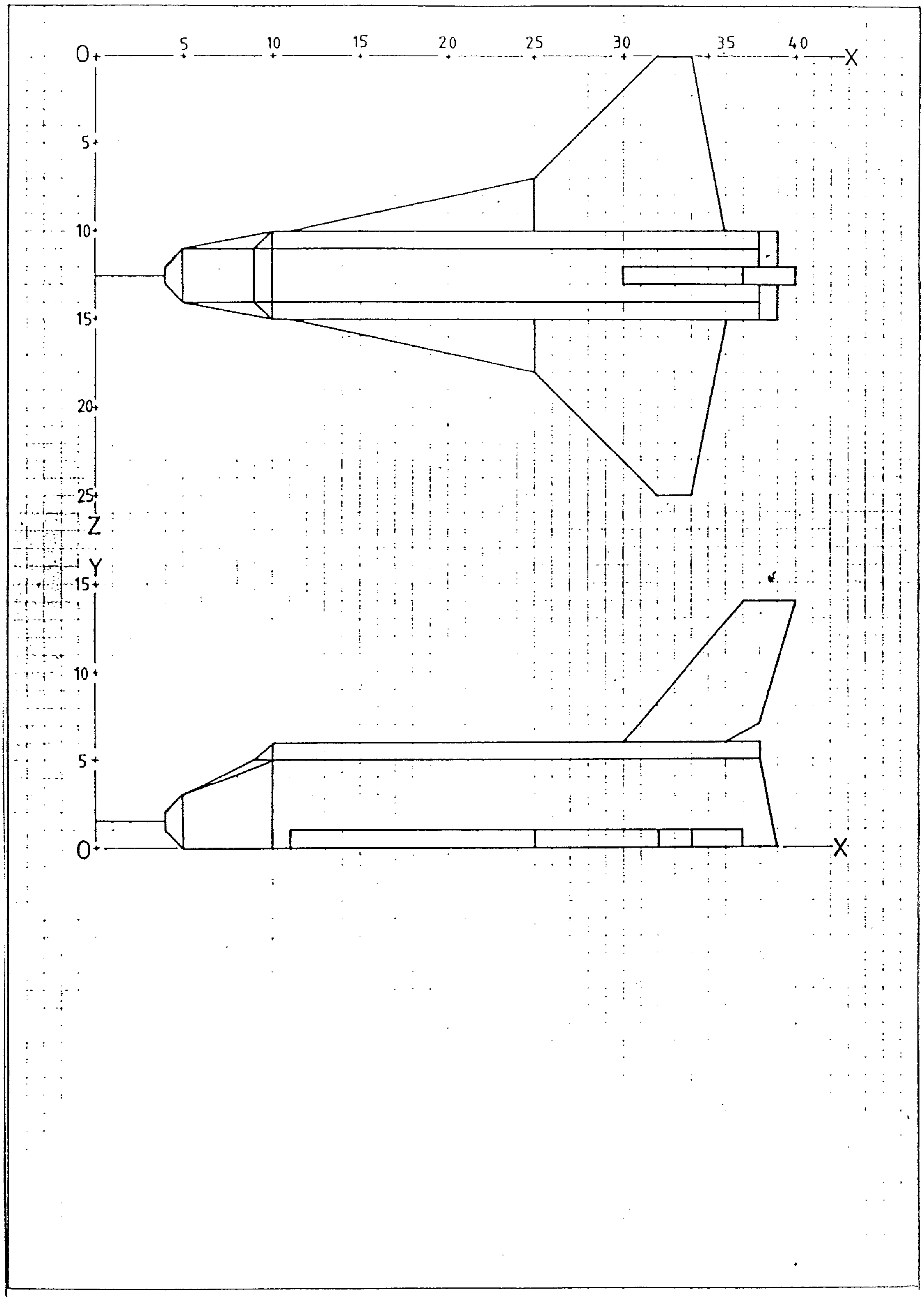
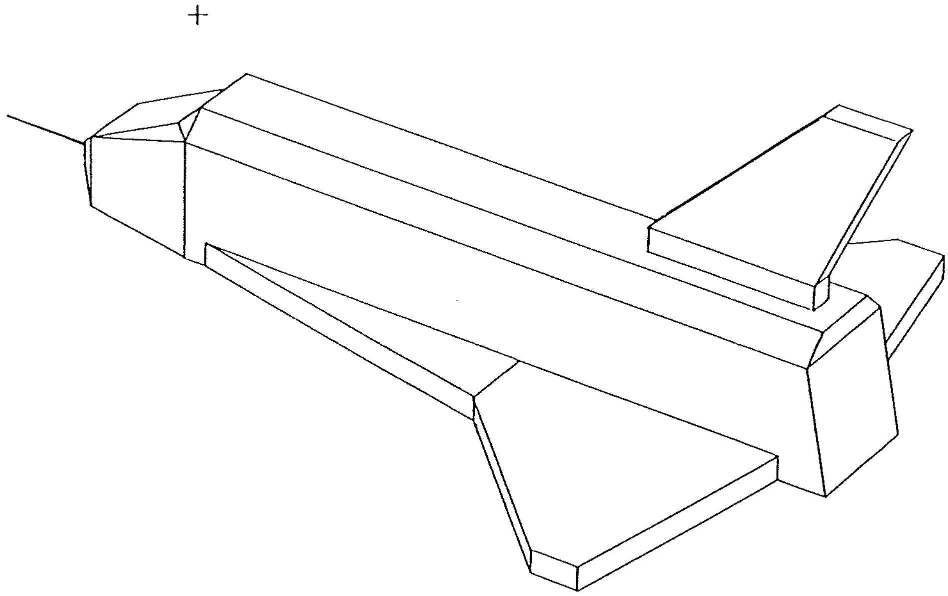


Fig. 3. Space shuttle a design which is closely modelled in terms of relative proportion to an actual shuttle.



CREIGHTON TECHNICAL GRAPHICS					
TITLE	Space Shuttle				
DESIGNER	G.A.Edwards	TUTOR GROUP	Staff	DATE	25th Dec 1980
DRG NO	PSHTLE	DRG TYPE	Pictorial view		
Drawn at Middlesex Polytechnic Computer Centre		DATE	9th July 1981		

Fig. 4. Perspective view of the space shuttle.

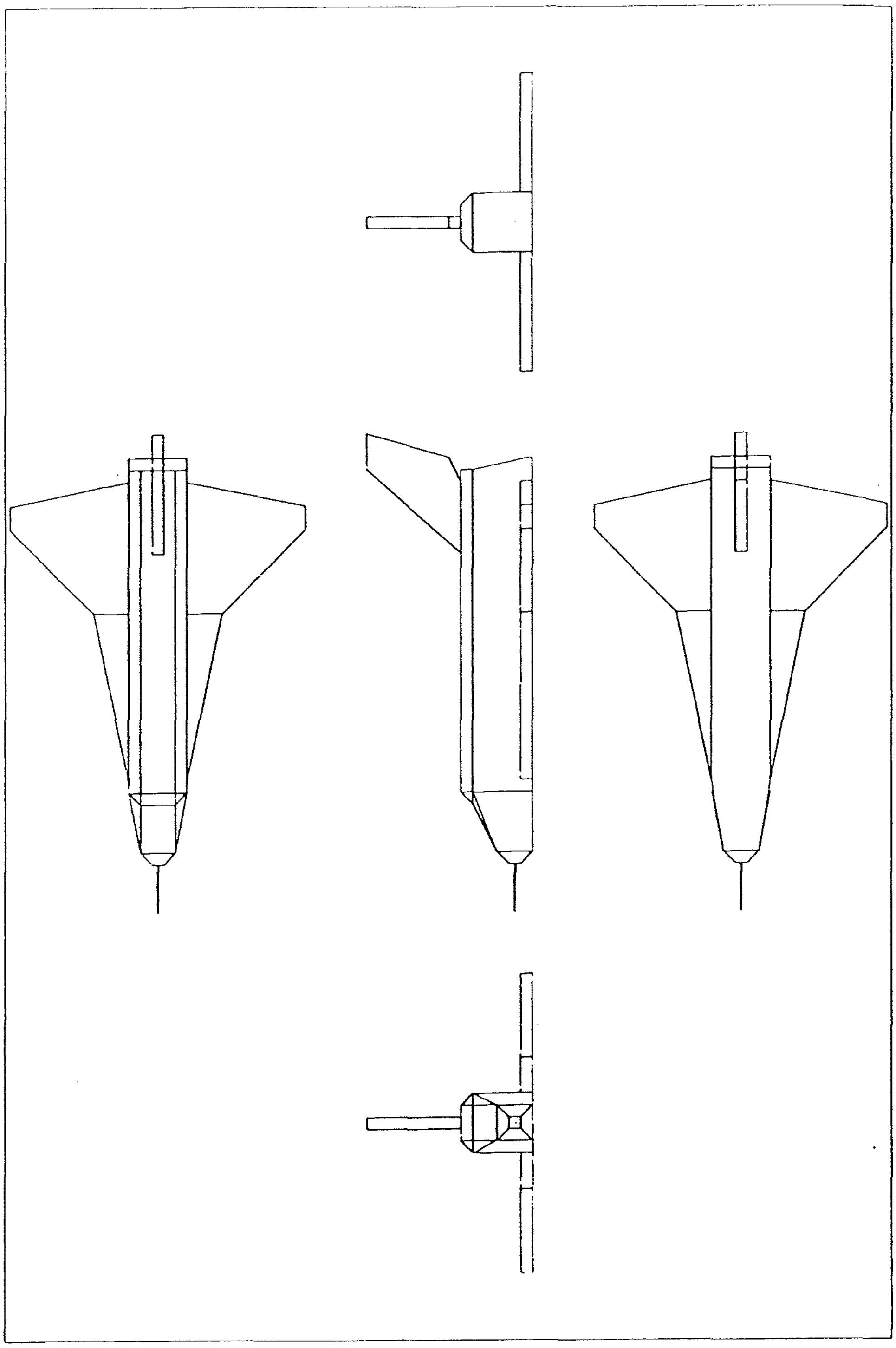
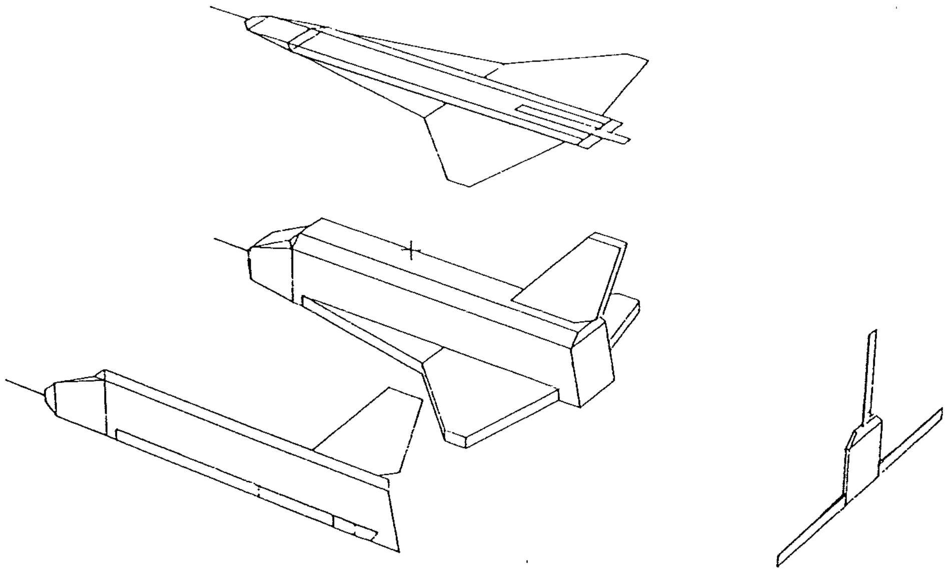


fig. 5. Five orthographic views of the space shuttle.



CREIGHTON TECHNICAL GRAPHICS

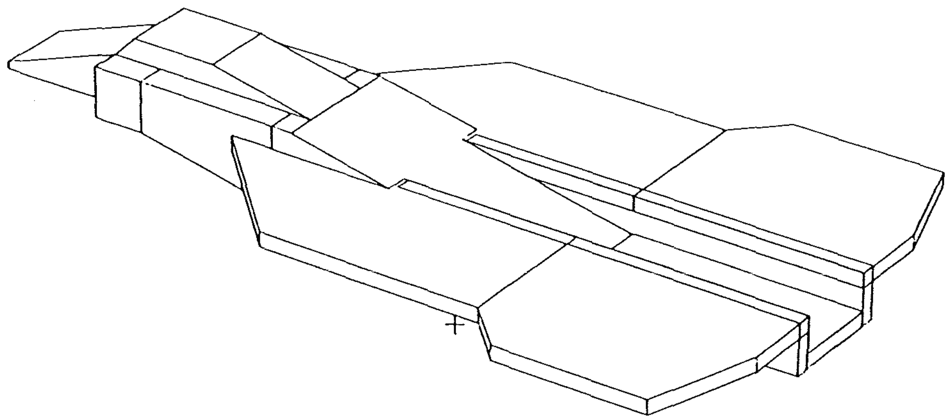
TITLE Shuttle +three views

DESIGNER G.A.Edwards TUTOR GROUP LBH DATE 6th May 1981

DRG NO PGE035 DRG TYPE Pictorial view

Drawn at Middlesex Polytechnic Computer Centre DATE 26th Nov 1981

Fig. 6. shuttle plus three orthographic projections viewed in perspective.



CREIGHTON TECHNICAL GRAPHICS

TITLE	Spaceport 1				
DESIGNER	G.A.Edwards	TUTOR GROUP	staff	DATE	11th June 1981
DRG NO	PSPGE5	DRG TYPE	Pictorial view		

Drawn at Middlesex Polytechnic Computer Centre DATE 31st July 1981

fig. 7. Spaceport 1 a design intended as a basis for a project involving the incorportion of smaller shuttle type craft, interior detail, and portholes and hatches to an external spacescape including artificial planets. The project was deferred till more computing power becomes available.

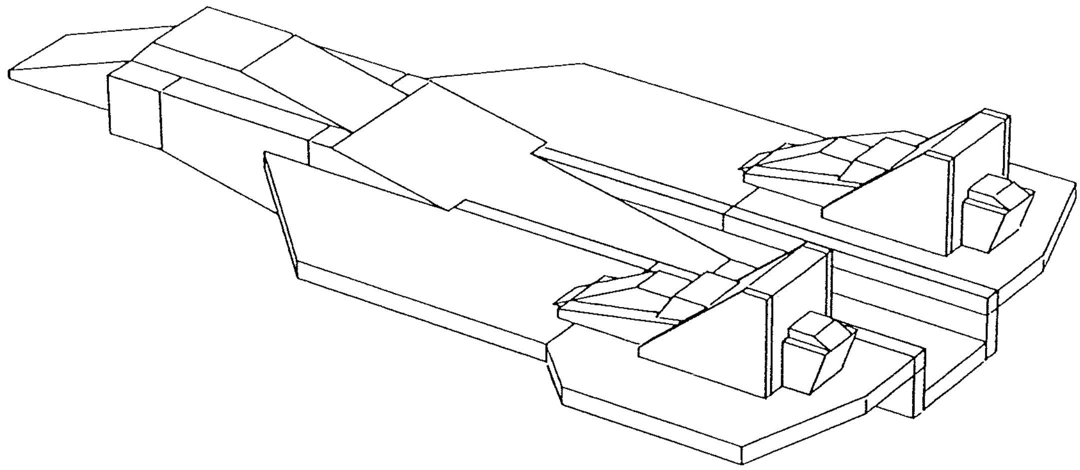
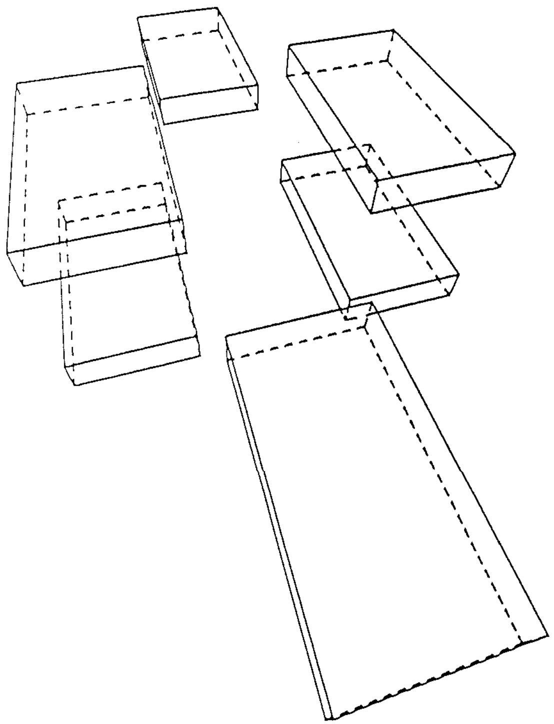


Fig. 8. spaceport 1 plus engines.

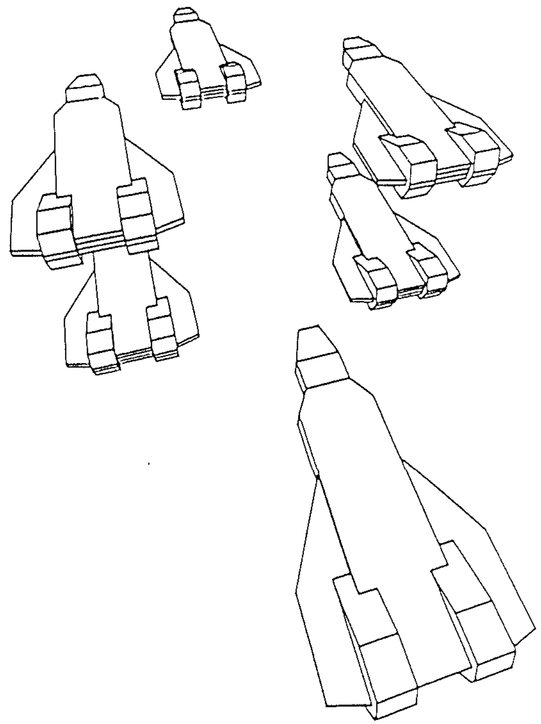
fig. 9. Two perspective views of a fleet of spacecraft. One view as a group of cuboids which are exactly equivalent to the spacecraft as regards proportion and spatial position.



CREIGHTON TECHNICAL GRAPHICS

TITLE	Fleet Of Craft6 As Cuboids
DESIGNER G.A.Edwards	TUTOR GROUP Staff DATE July 1982
DRG NO —	DRG TYPE Natural perspective

Drawn at Middlesex Polytechnic Computer Centre DATE 30th July 1982



CREIGHTON TECHNICAL GRAPHICS

TITLE	Fleet Of Craft 6's
DESIGNER G.A.Edwards	TUTOR GROUP Staff DATE July 1982
DRG NO —	DRG TYPE N.Persp.D=100,R=75,E=45

Drawn at Middlesex Polytechnic Computer Centre DATE 30th July 1982

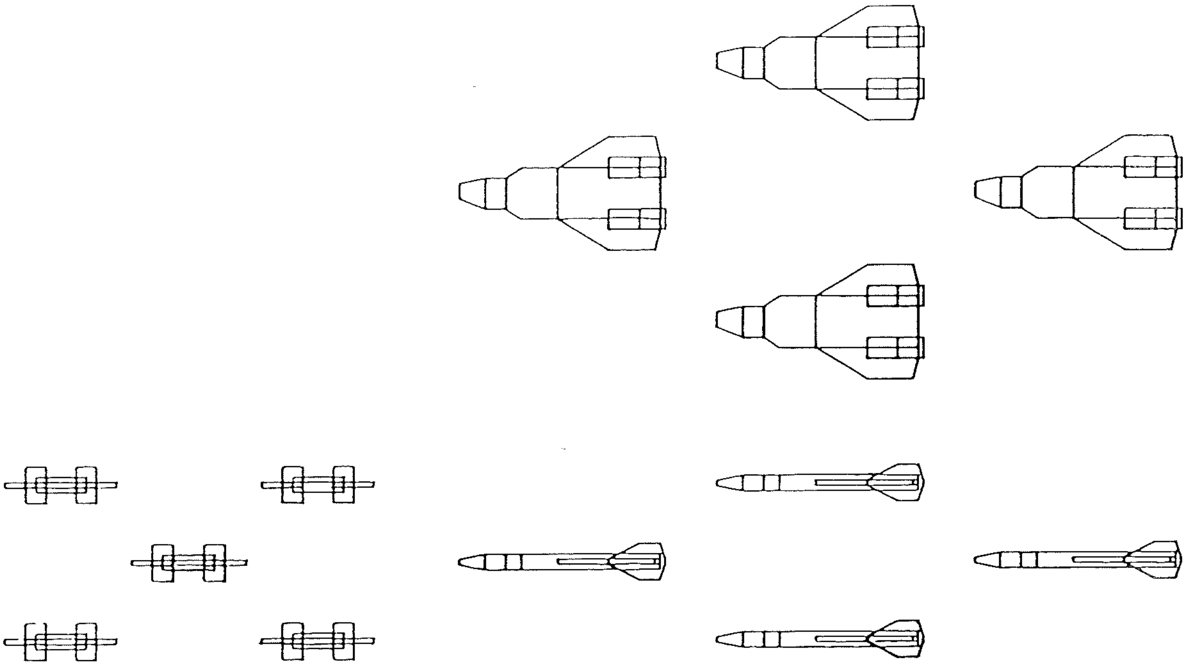
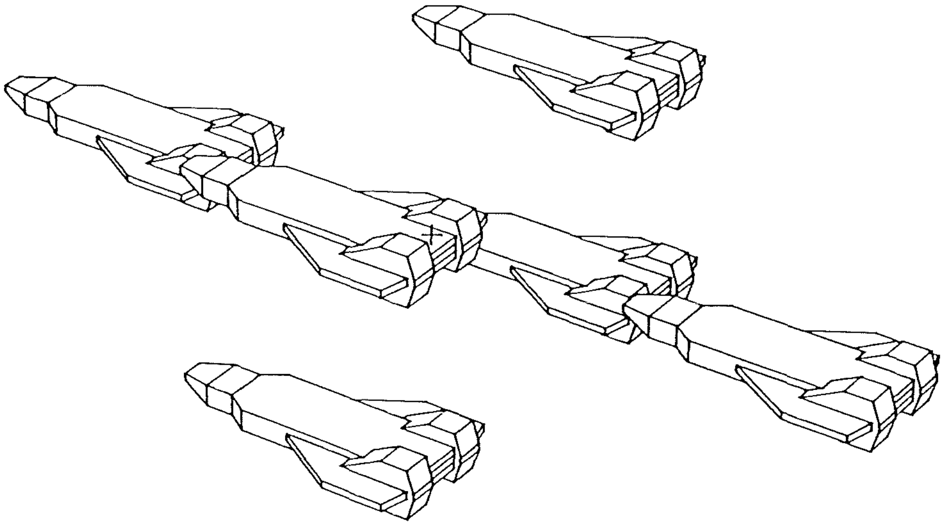


fig. 10. An unusual orthographic three-view computer generated drawing of a fleet of spacecraft 6's in the same spatial arrangement as fig. 9.



CREIGHTON TECHNICAL GRAPHICS

TITLE	Fleet Of Spacecraft 6		
DESIGNER G.A.Edwards	TUTOR GROUP Staff	DATE Dec 1981	
DRG NO —	DRG TYPE Natural perspective		
Drawn at Middlesex Polytechnic Computer Centre	DATE 27th July 1982		

Fig. 11. A more normal perspective view of a fleet of spacecraft 6's. These are arranged in the same spatial arrangement as figs 9–10.

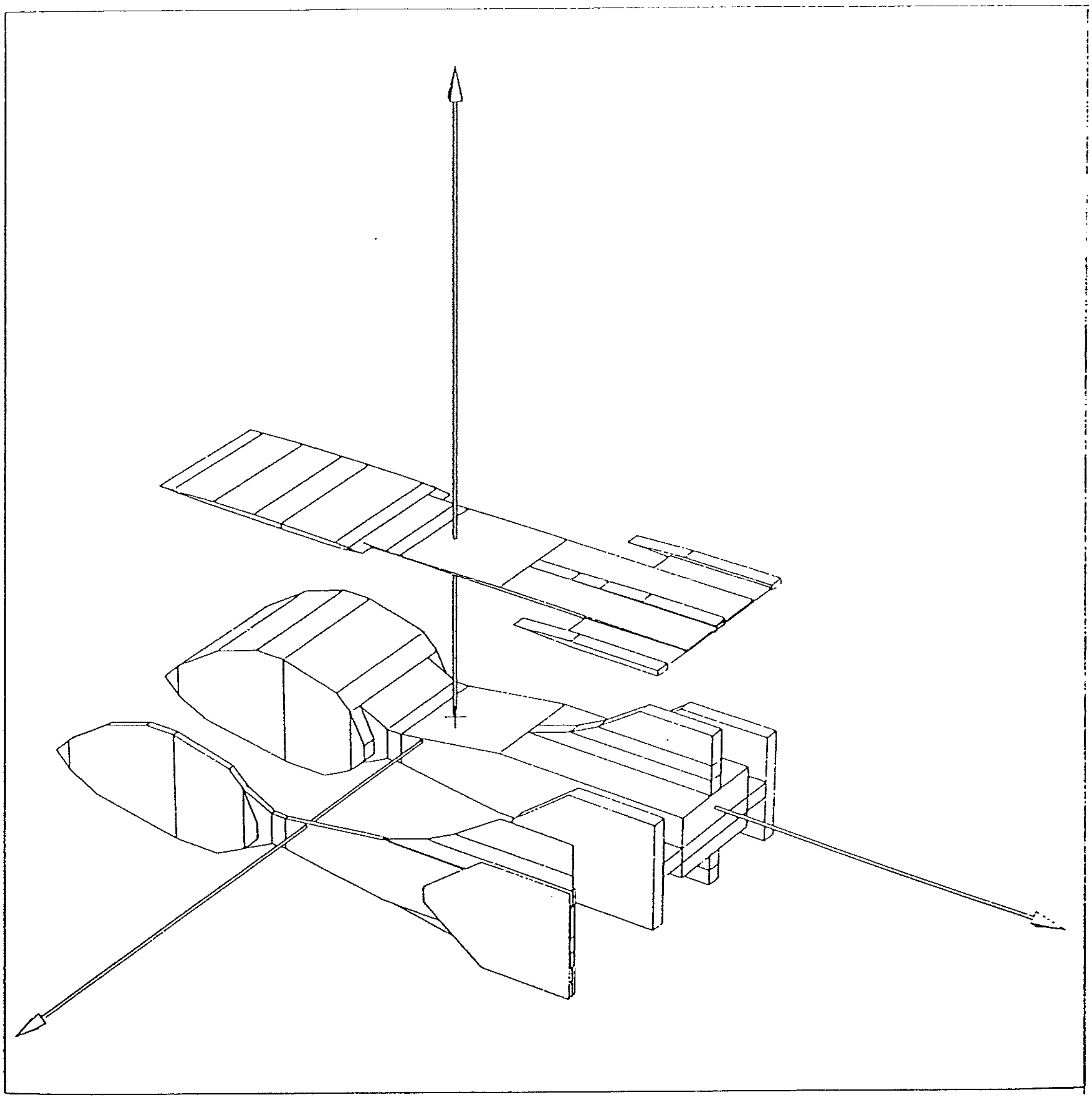


Fig. 12. A perspective view of the output from the FLATOBJECTS program.

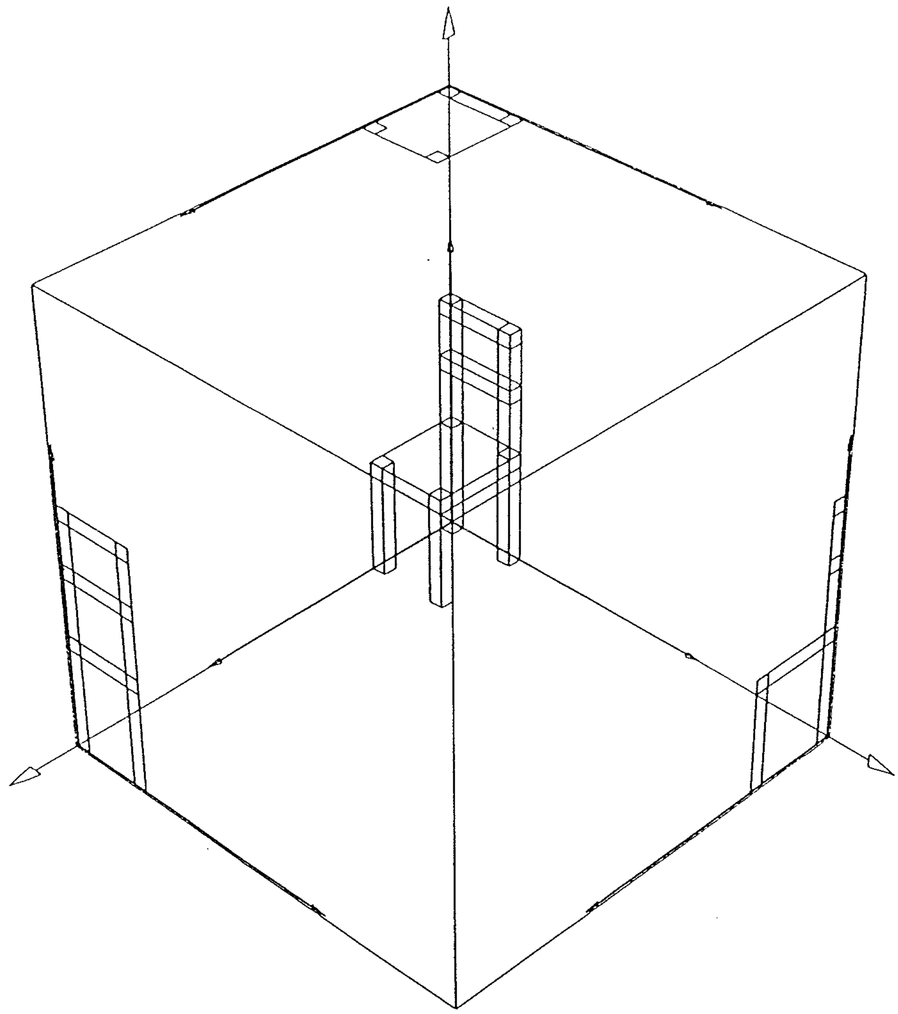


Fig. 13. A chair in a glassbox. The chair has 3D solid axes and these have been projected onto the sides of the box in addition to orthographic views of the chair. Note that the box has axes as well. The spatial structure has been plotted with the eye in a position corresponding to an isometric view, although the plot is a perspective view as the eye is not at "infinity".

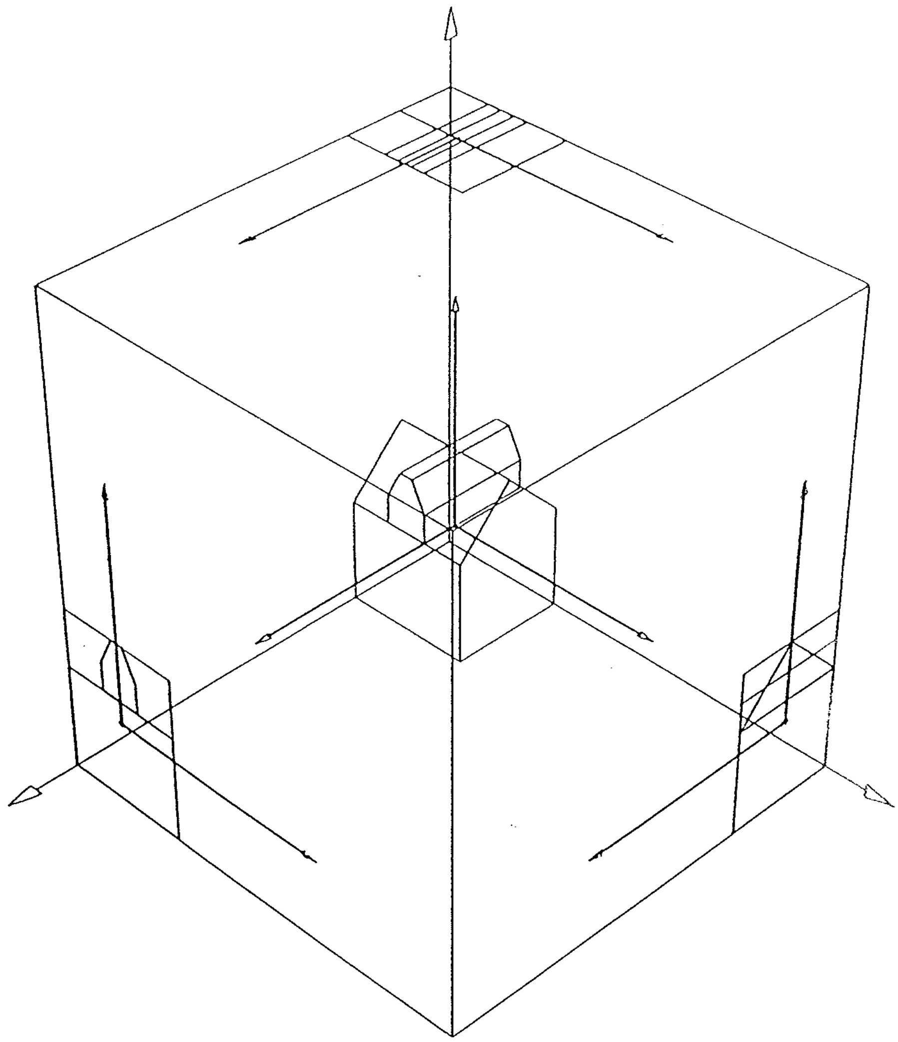


Fig. 14. A house in a glassbox. The house has 3D solid axes and in contrast to fig. 13. the axes are central to the house. It is intended to add 3D letters (X, Y, Z) to the program at a later date.

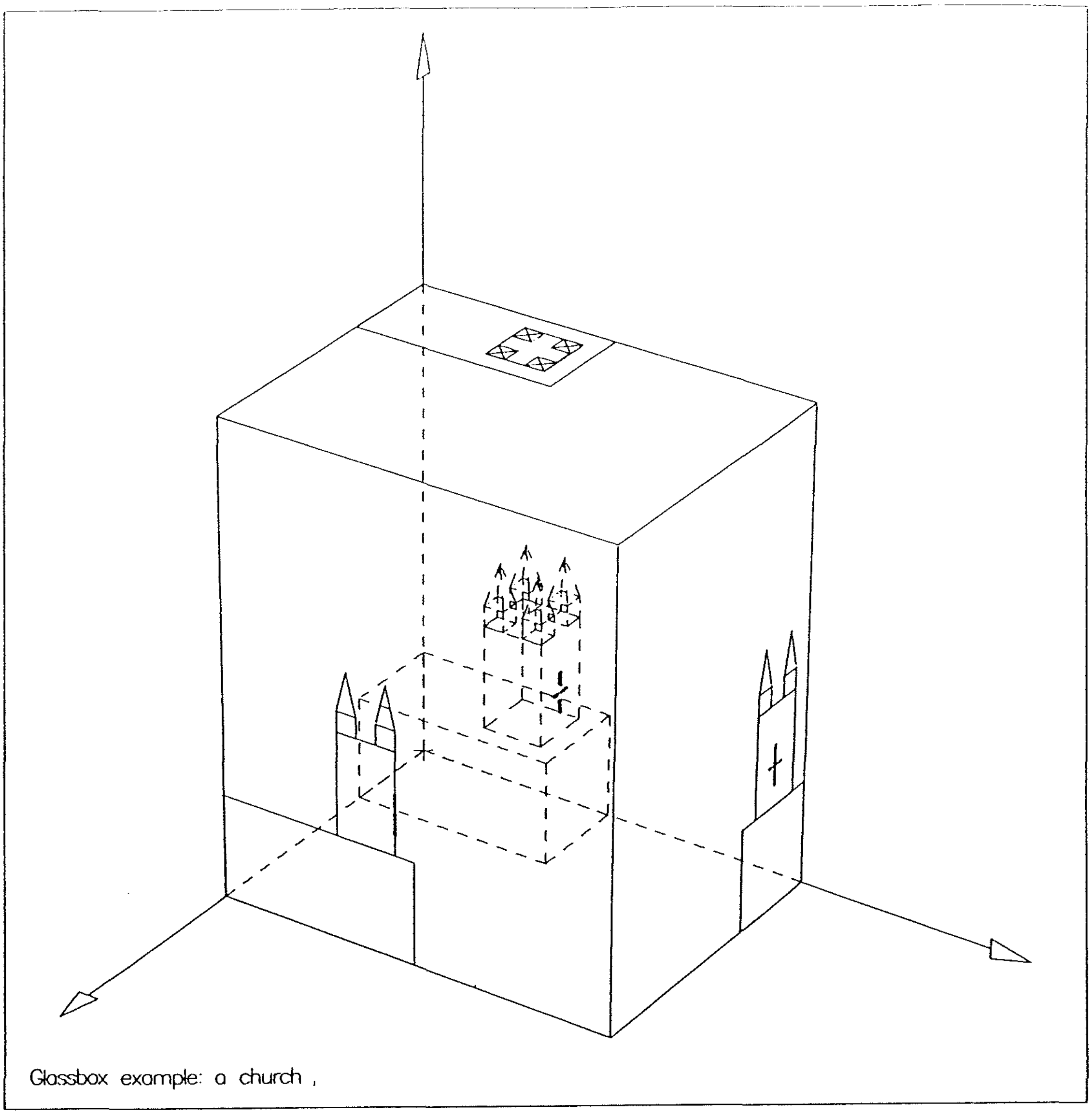


Fig. 15. A church in a glassbox. In this plot the glass is virtually opaque, resulting in the object being drawn in hidden detail mode. The views had to be projected slightly outside the sides of the box in order to be visible.

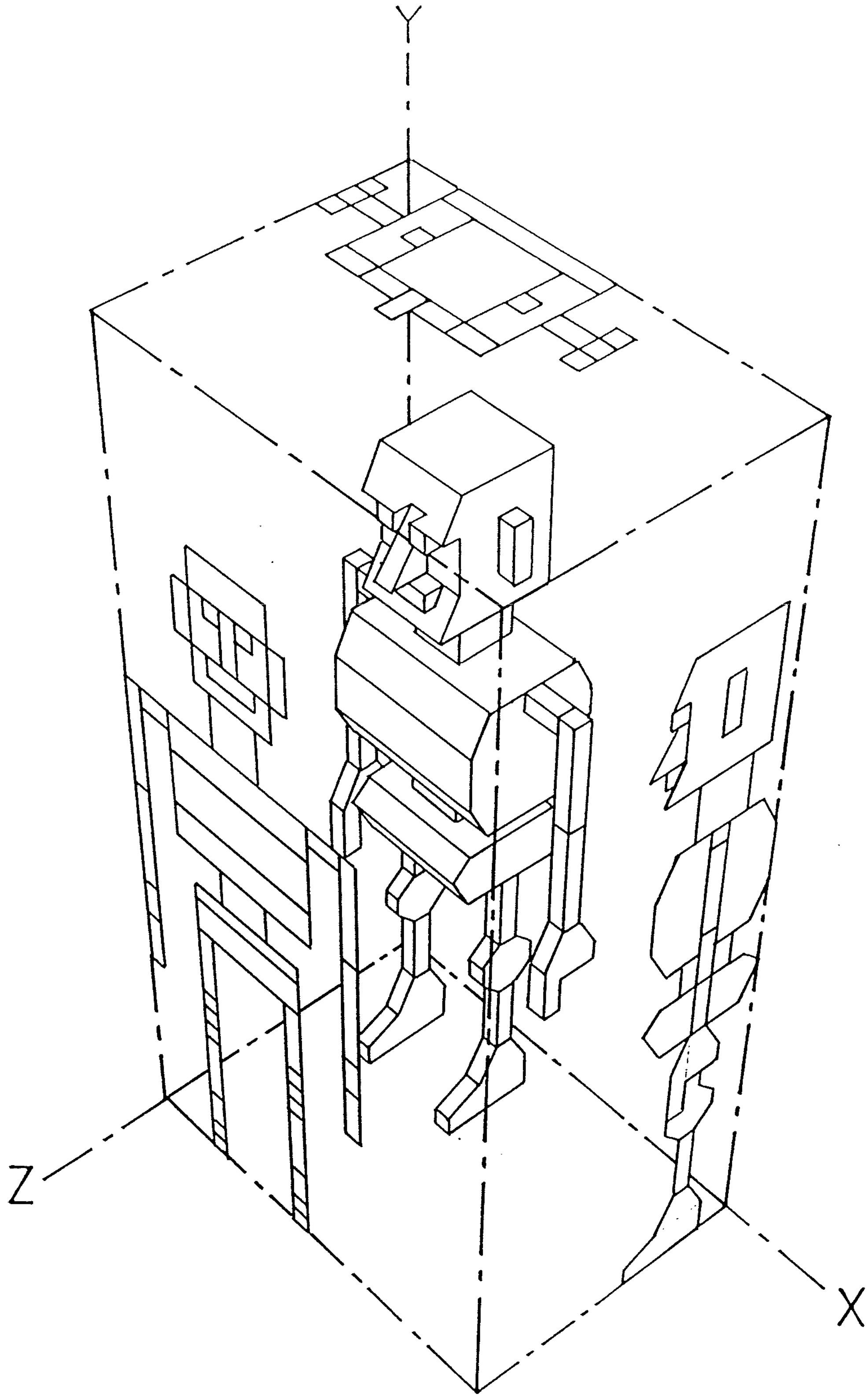


fig. 16. A robot in a glassbox. This drawing has been traced by the author to omit lines which because of interpenetration problems were not removed by the computer. Since the plotter cannot use pencil lead the drawing was plotted in gold ball-point ink to minimise the necessity to remove unwanted lines and facilitate the tracing.

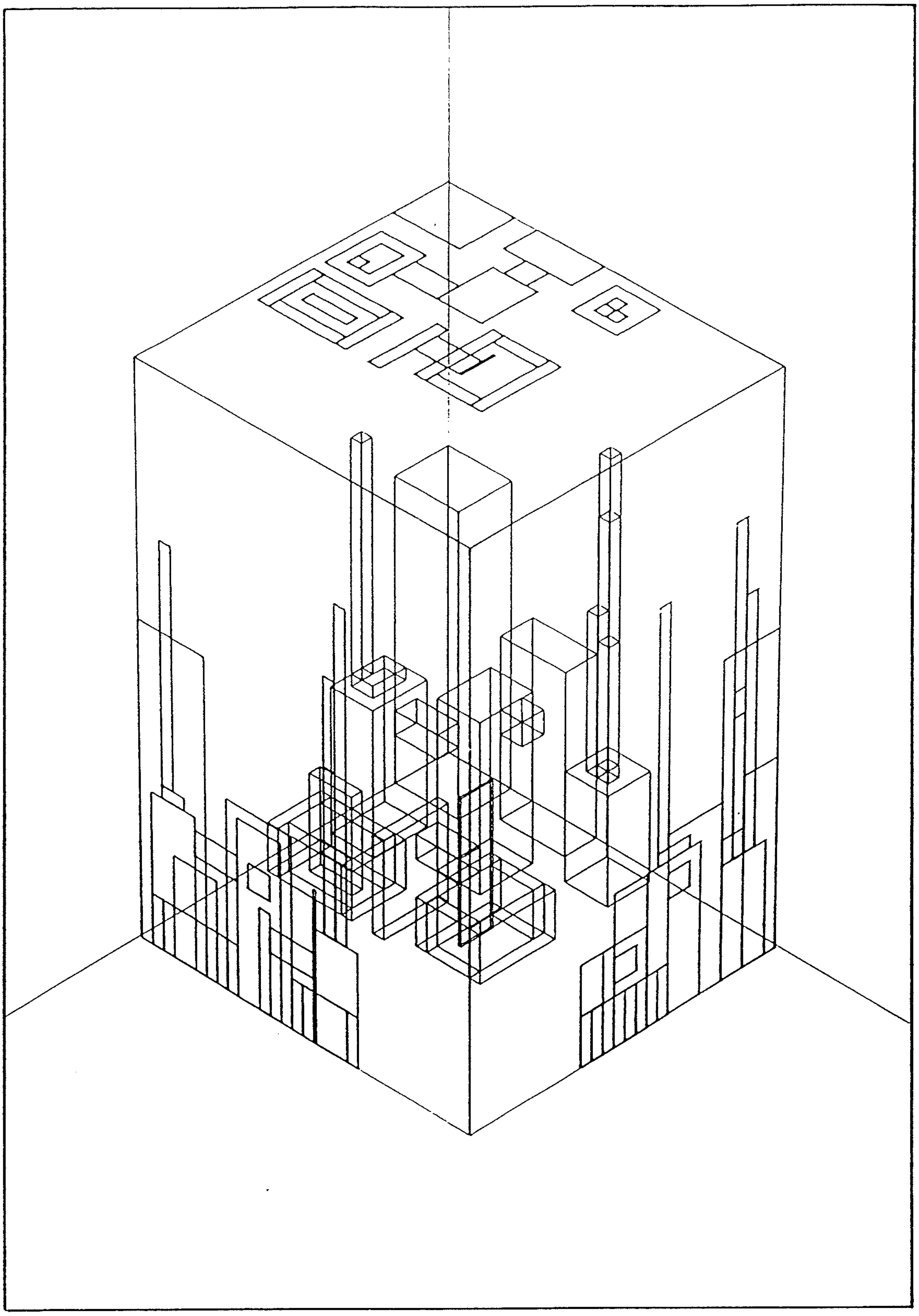


Fig. 17. A City Unit design in a glassbox. The GLASSBOX program has an option to plot the views in a different colour to the object in the box, this facility helps the pupil to distinguish the views.

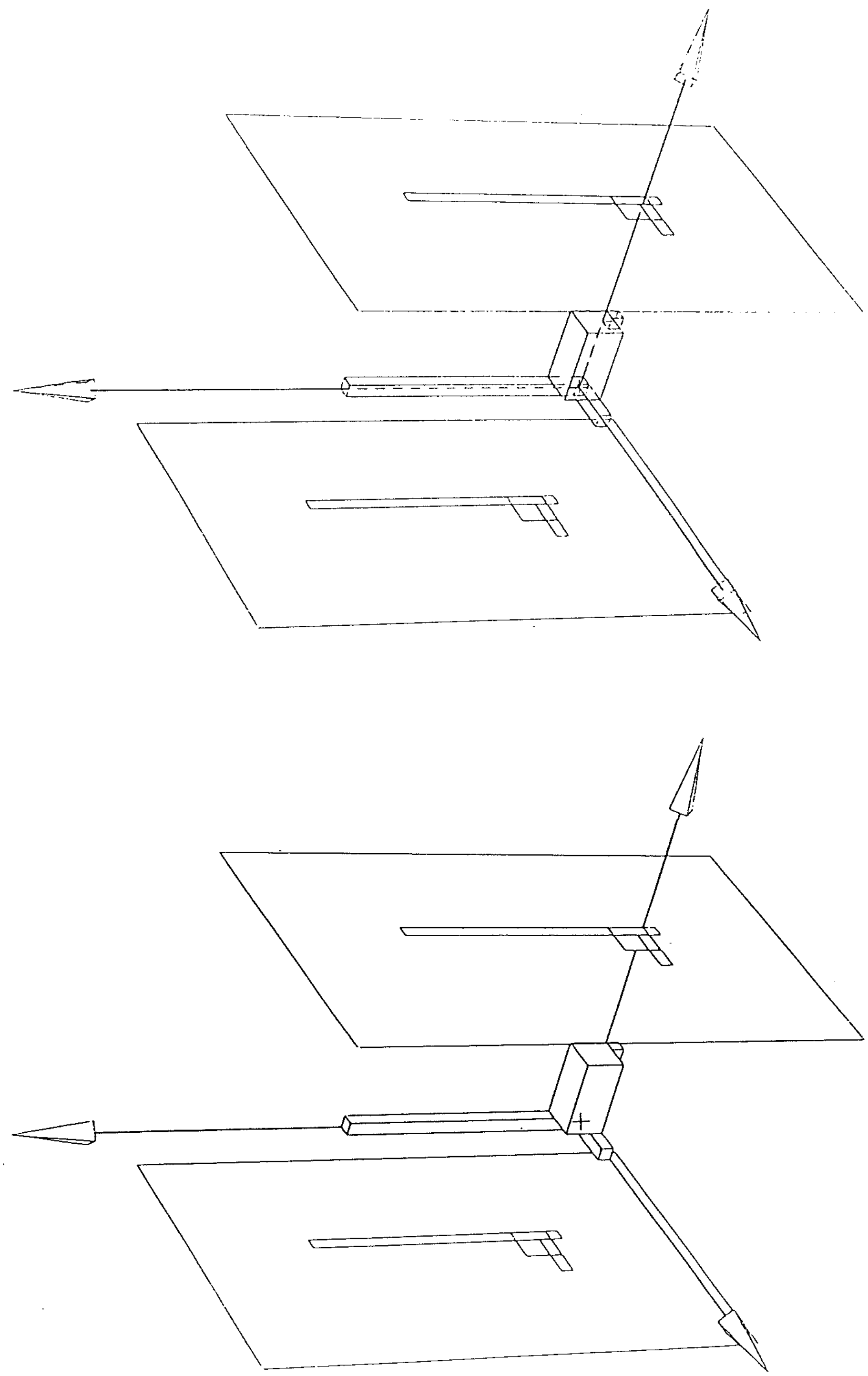


Fig. 18. Two perspective views of of an object and its projections onto view planes. One drawing includes hidden detail.

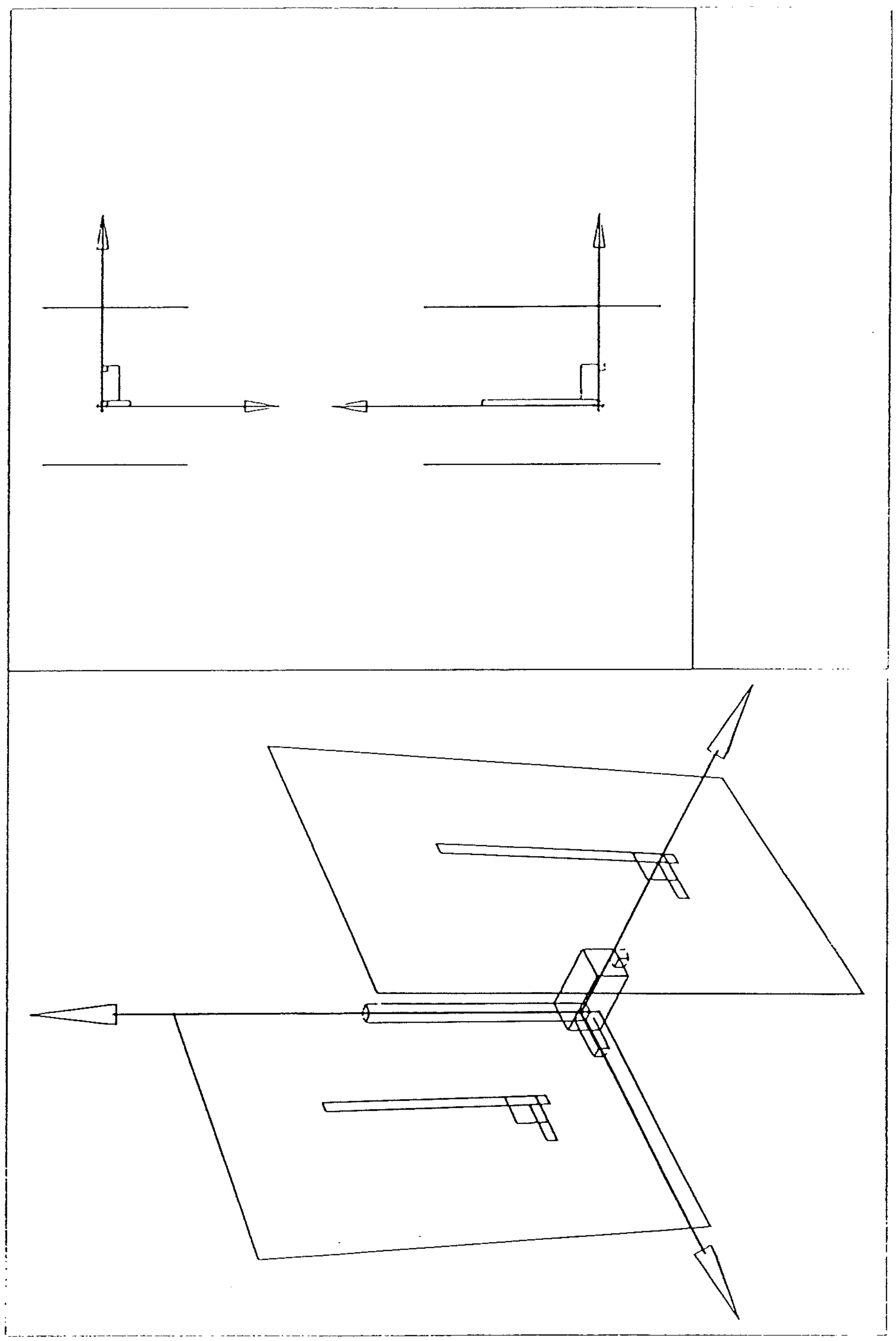


Fig. 19. Combination of perspective and orthographic views of two 3D projection planes and an unsymmetric object.

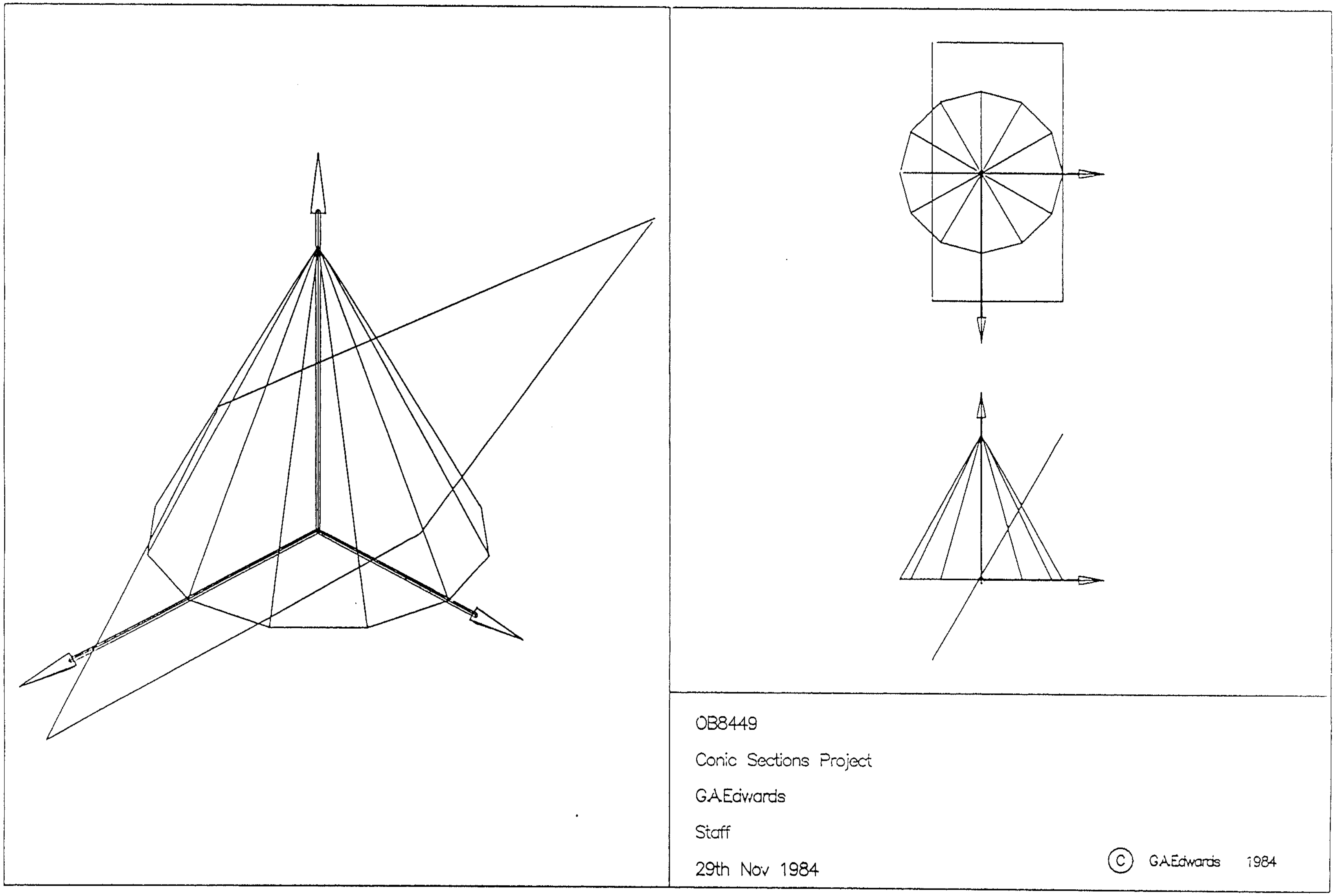


Fig. 20. Intersection of a cone and a plane. See also figs. 21-22.

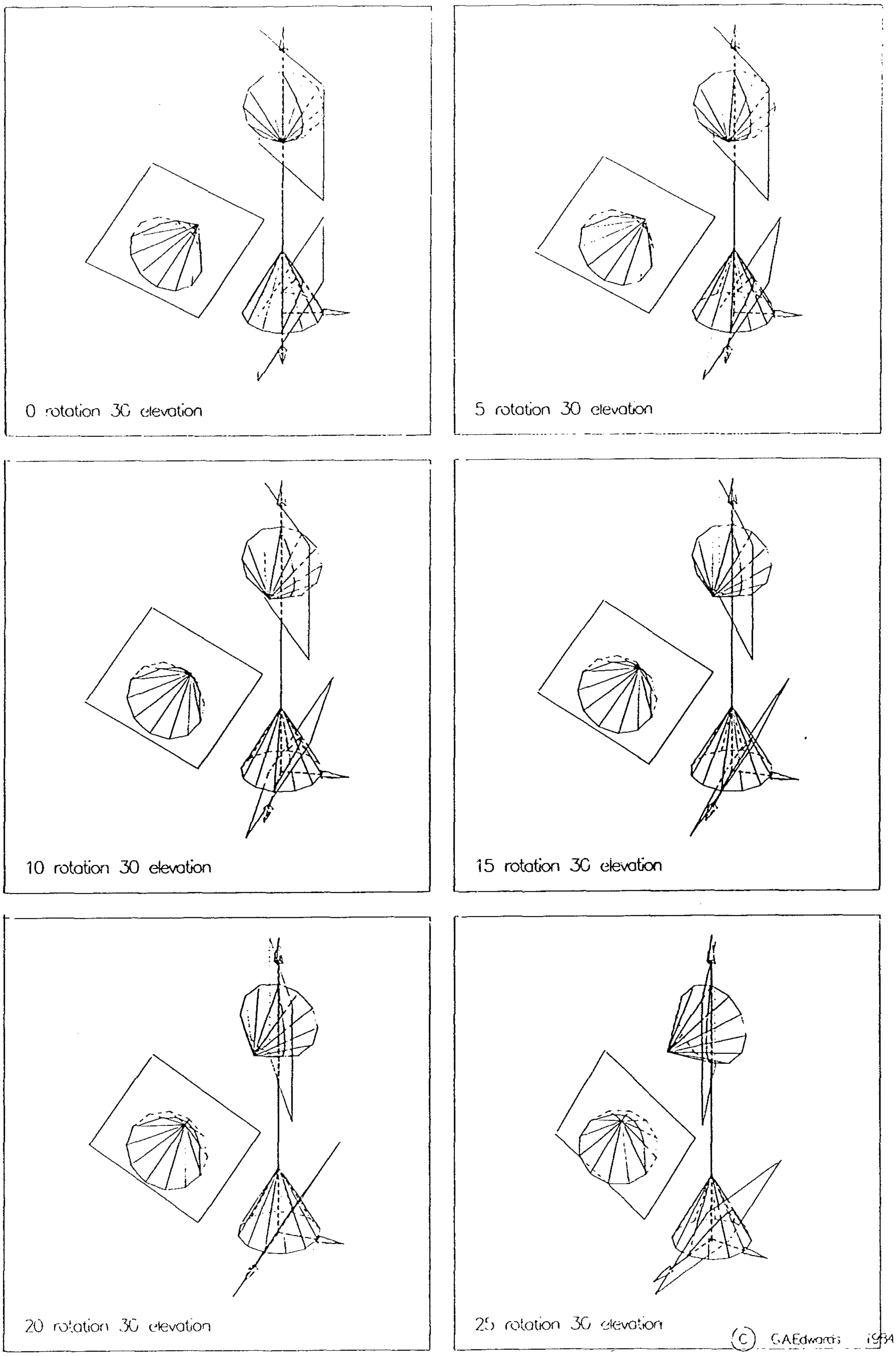


Fig. 21. Six frames showing rotation about the vertical axis of the spatial structure generated to enable a parabolic section of a cone to be drawn. See Fig. 22

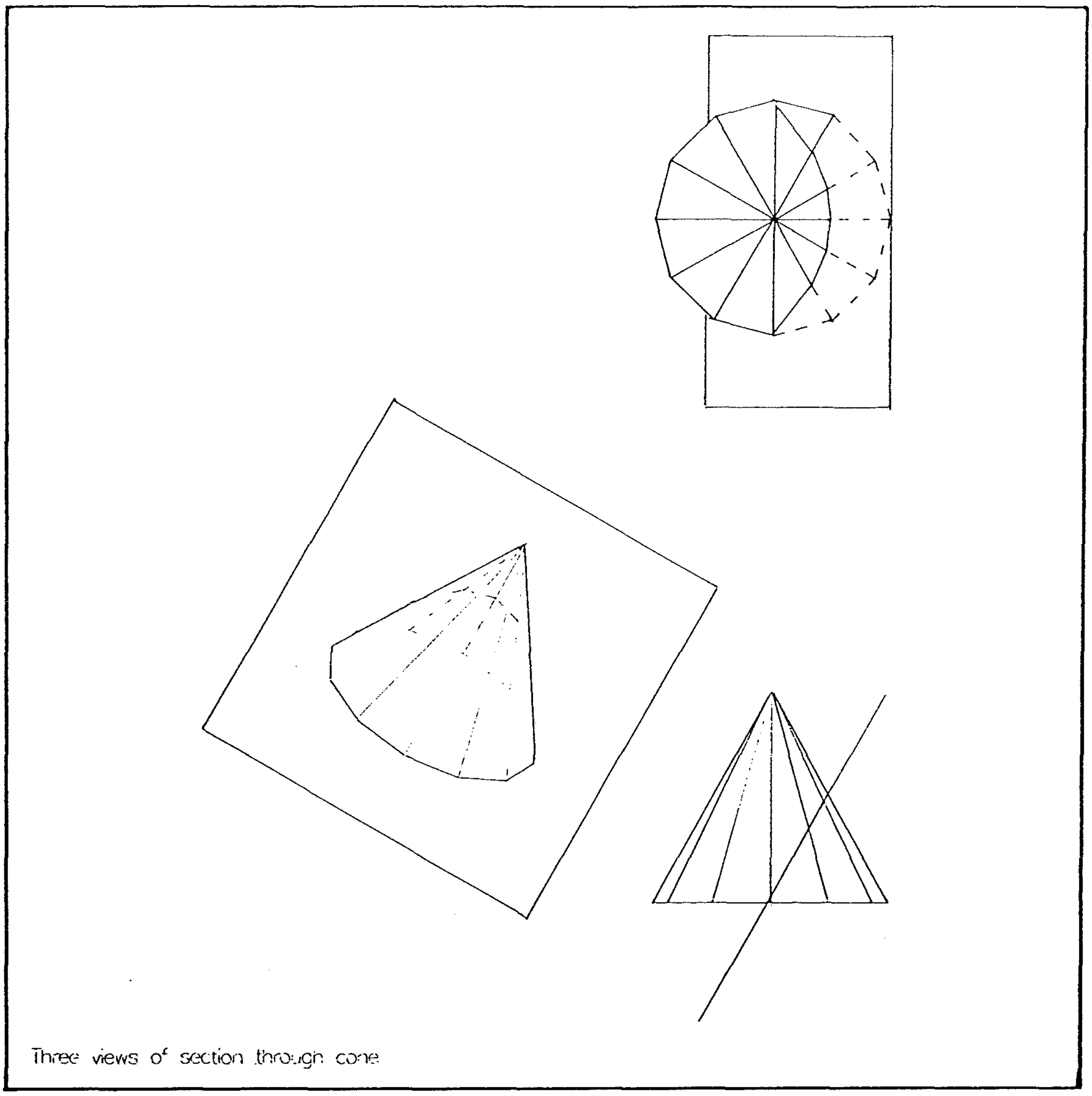


Fig. 22. Orthographic view and auxiliary view of a parabolic section through a right cone. Note the drawing is an orthographic view of three 12 sided models of cones and three planes as arranged in fig. 21.

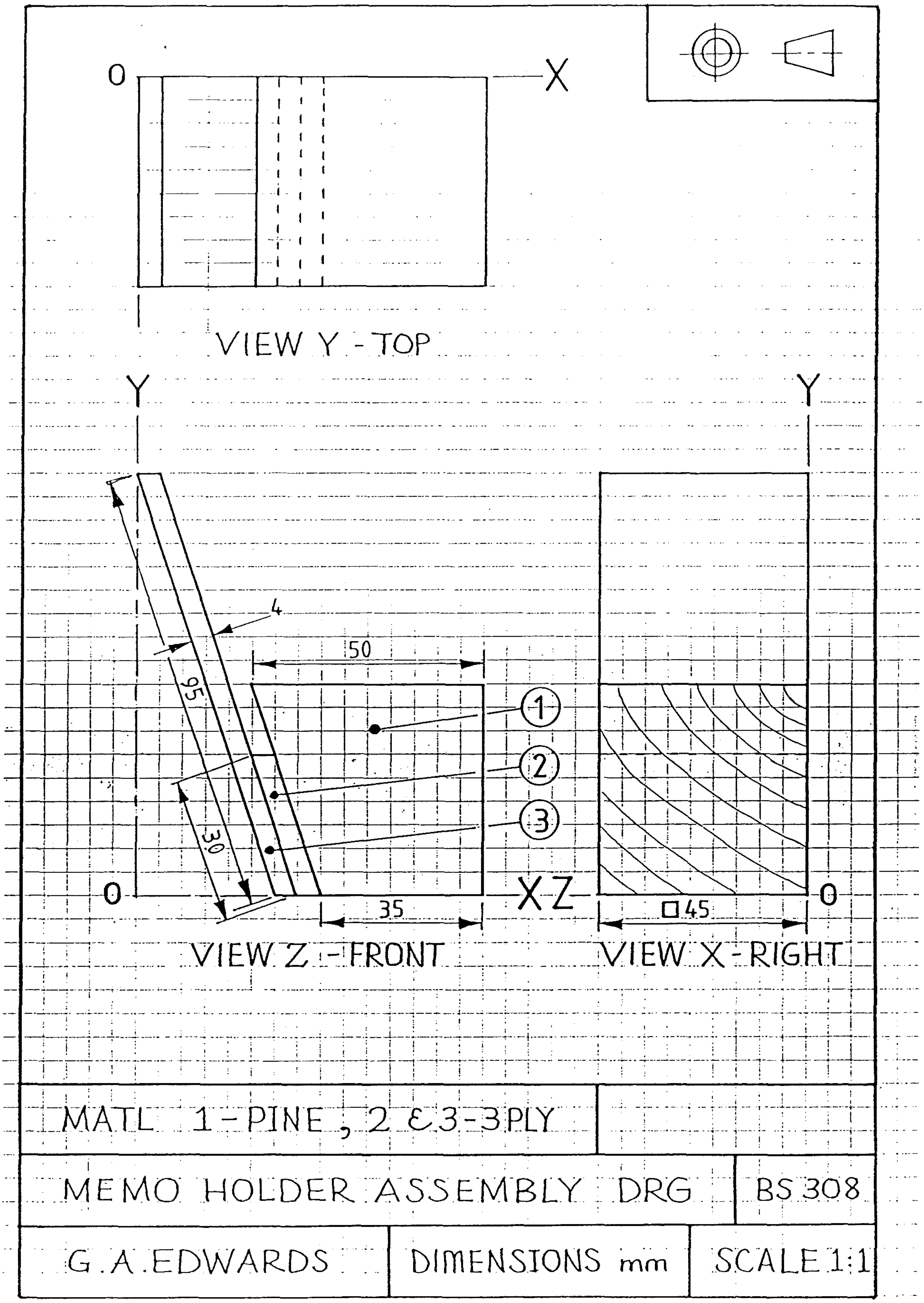


Fig. 23. Memo holder project. Orthographic views drawn to BS 308 except for the labelling of the axes.

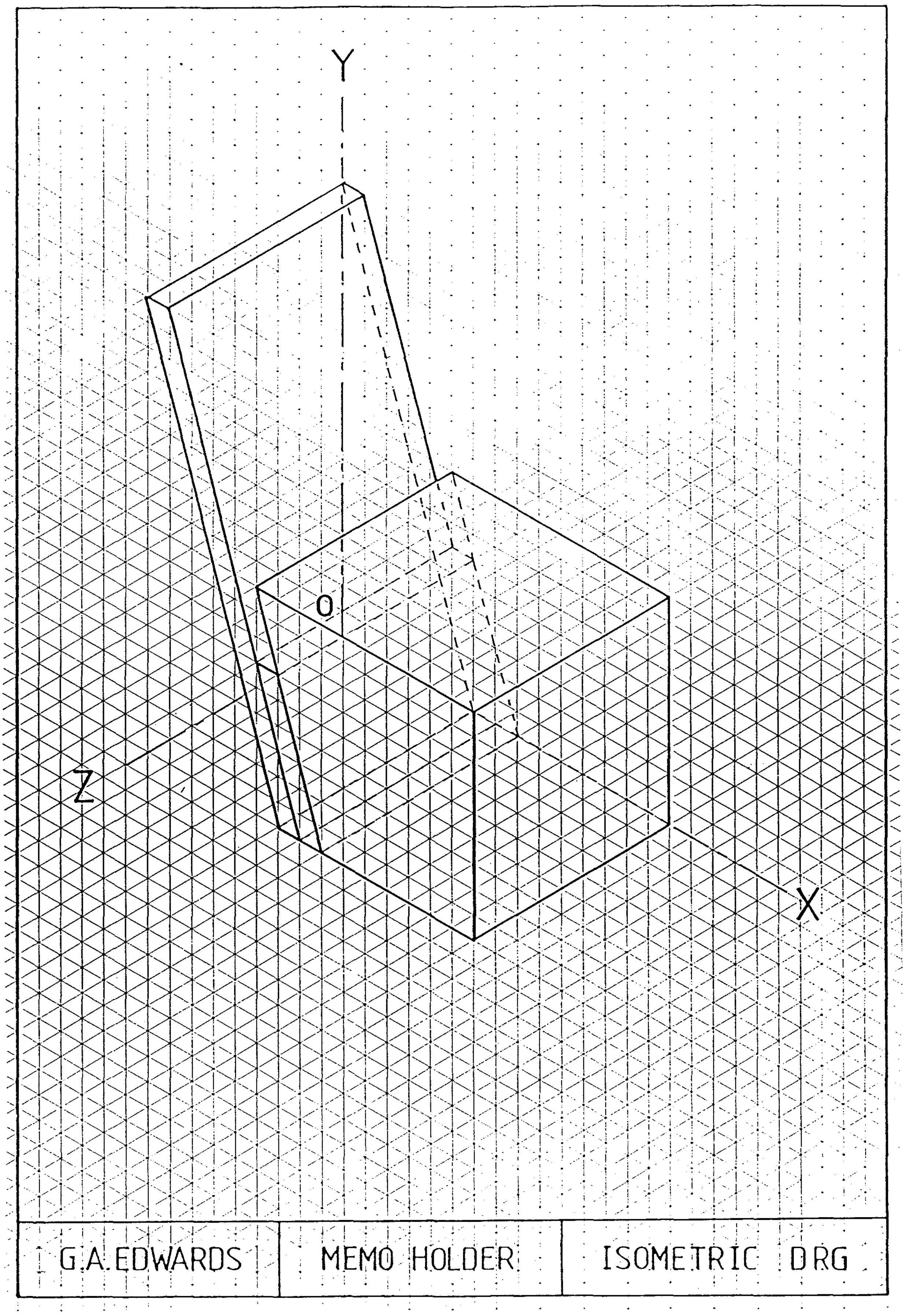


Fig. 24. Memo holder project. Isometric view.

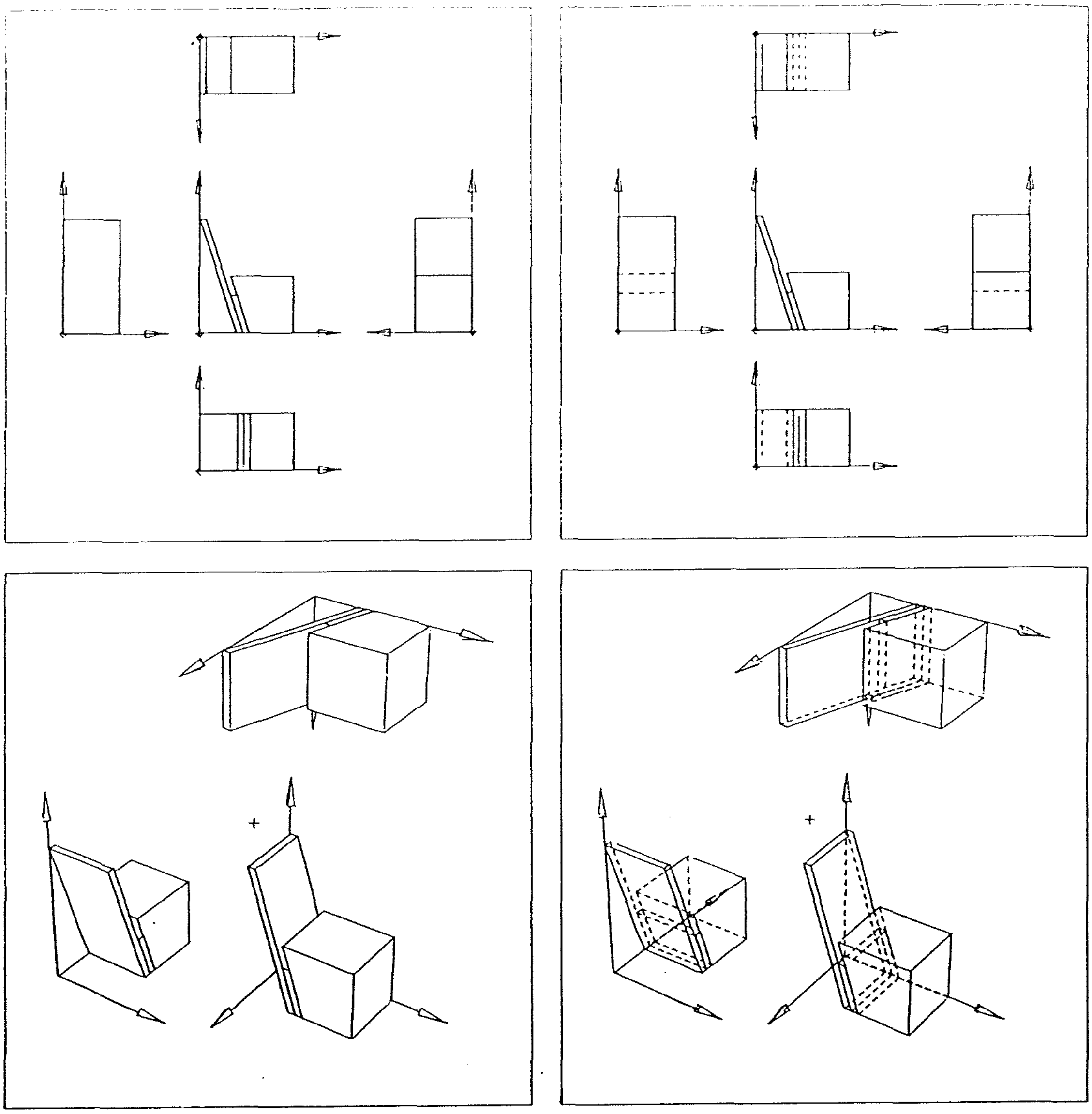
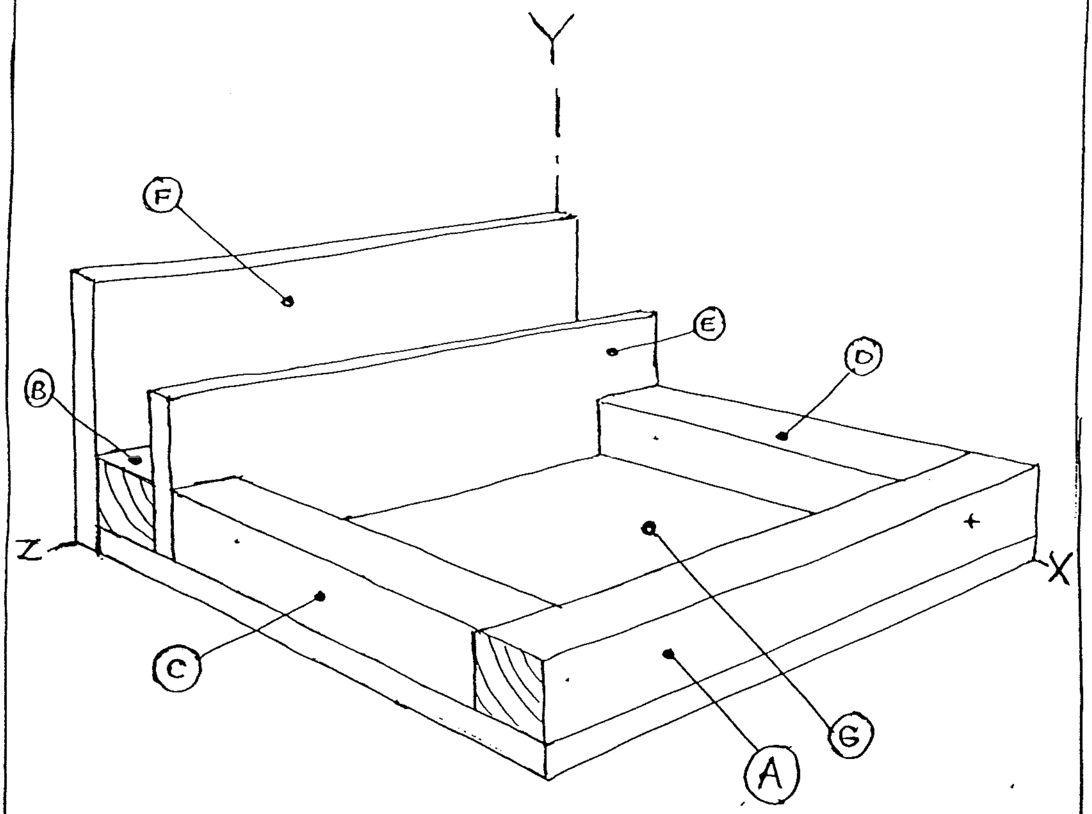


Fig. 25. Four frames showing five-view orthographics and the spatial arrangement from which the orthographic views have been derived.



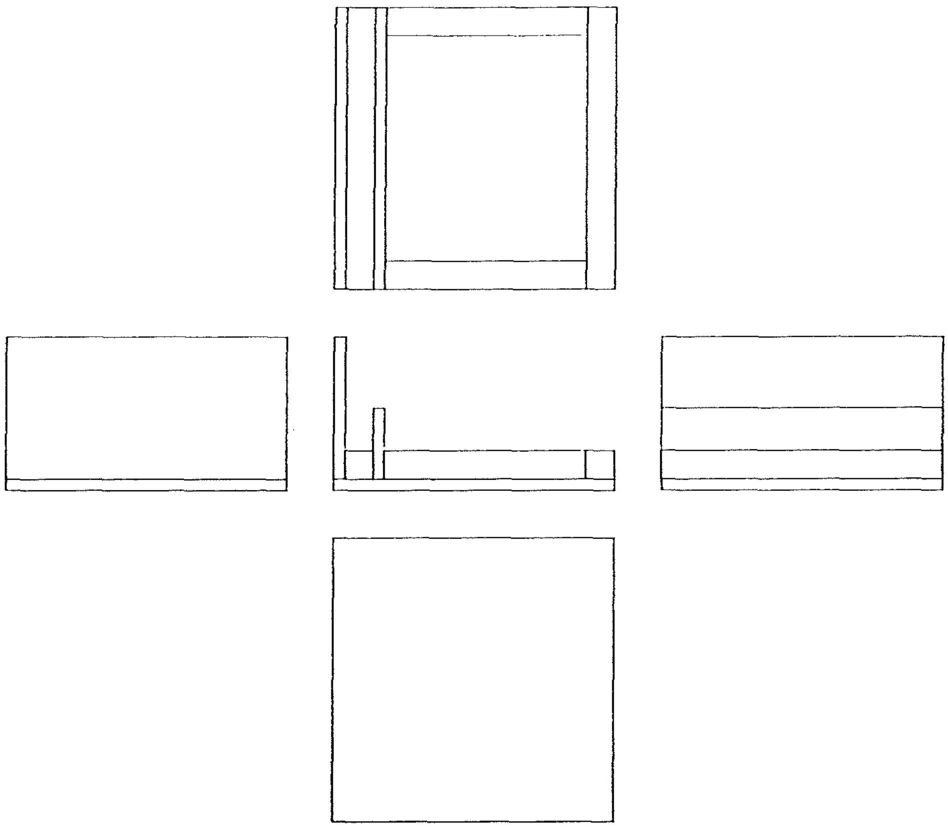
	WIDTH X	HEIGHT Y	DEPTH Z	XPOS	YPOS	ZPOS
A	15.	15.	100.	89.	4.	0.
B	15.	15.	100.	4.	4.	0.
C	66.	15.	15.	23.	4.	85.
D	66.	15.	15.	23.	4.	0.
E	4	25.	100.	19.	4.	0.
F	4.	50.	100.	0.	0.	0.
G	100.	4.	100.	4.	0.	0.

G.A.EDWARDS	MONEY HOLDER

Fig. 26. Emergency Money holder project. Freehand pictorial view of the author's money holder example. The data for the computer was obtained solely by means of this pictorial view.

```
0B8520
Emergency Money Holder
G.A.Edwards
Fortismere School
Staff
15th July 1985
CB
7
   15.      15.      100.     89.     4.     0.     A
   15.      15.      100.     4.      4.     0.     B
   66.      15.      15.      23.     4.     85     C
   66.      15.      15.      23.     4.     0.     D
   4.       25.      100.     19.     4.     0.     E
   4.       50.      100.     0.      0.     0.     F
   100.     4.       100.     4.      0.     0.     G
END
.bottom.
*
OK. DATE
15 Jul 85 14:48:04 Monday
OK.
```

Fig. 27. Computer printout of the data file for the money holder. Note how small the file is.



School:..................Fortismere School

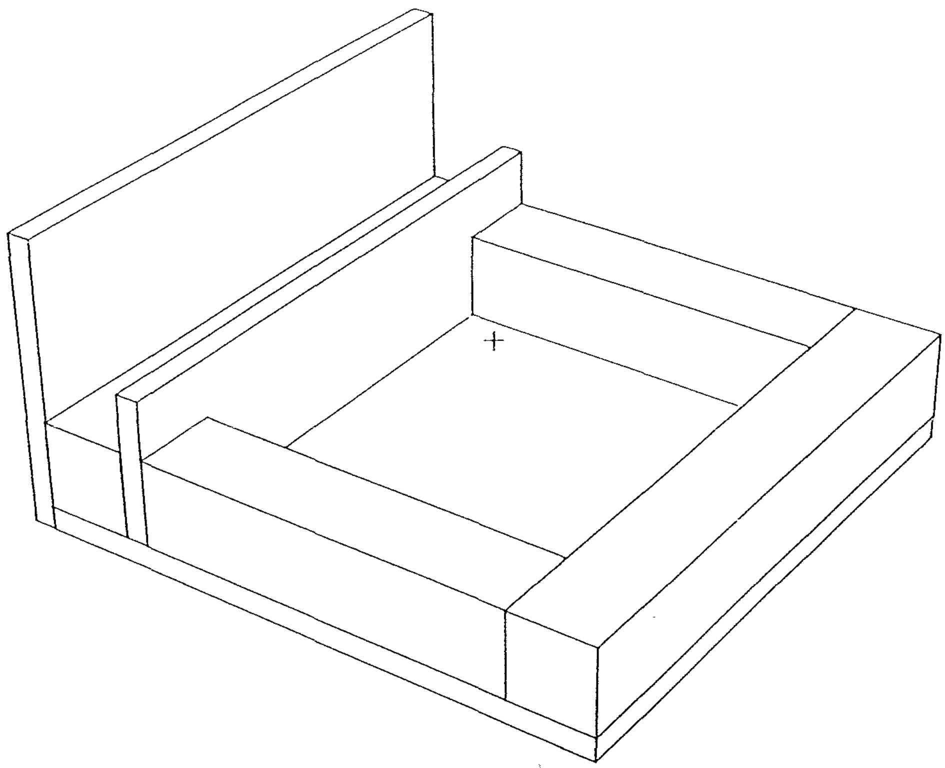
Title:...................Emergency Money Holder

Designers' name:........G.A.Edwards

Tutor group:............Staff

Drawn at Middlesex Polytechnic Computer Centre Date FRI, 12 JUL 1985

Fig. 28. Five-orthographic views of the money holder example.



School:..................Fortismere School

Title:...................Emergency Money Holder

Designers' name:........G.A.Edwards

Tutor group:............Staff

Drawn at Middlesex Polytechnic Computer Centre Date MON, 15 JUL 1985

Fig. 29. Perspective view of the money holder example.

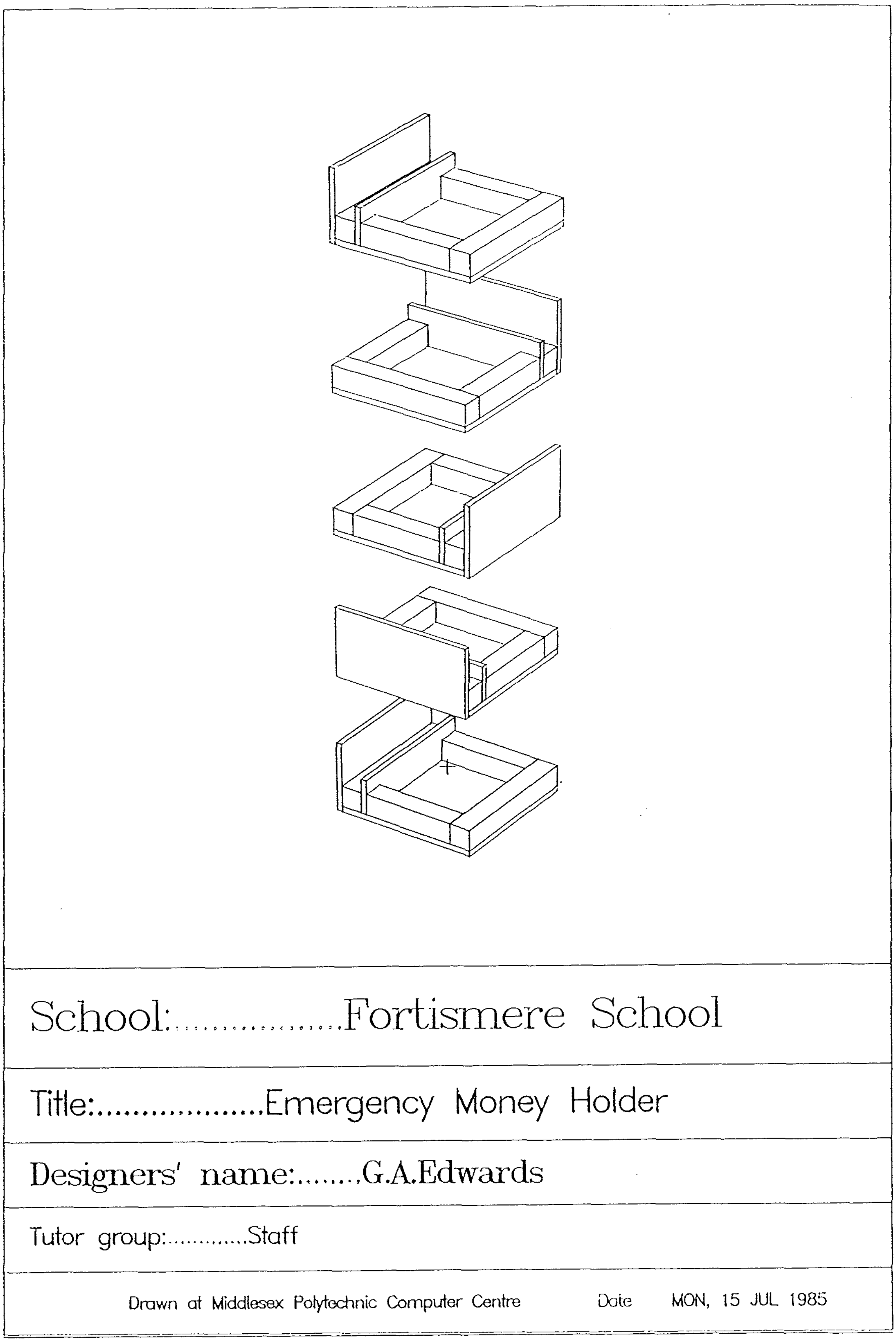


Fig. 30. Perspective view of the 360 degree rotation in 90 degree increments of the money holder example.

APPENDIX 5

PROGRAM REFERENCE MATERIAL: OPTIONS

OPTIONS REFERENCE MATERIAL

Input, output operations:

IN: reads a PICASO object from disc file into the work area

PI: reads a PICASO object from disc into a protected area

OU: writes a PICASO object from the saved area to disc

Object manipulation operations:

CE: centralises a PICASO object in the working area at the XYZ origin

PC: centralises a PICASO object in the protected area at the XYZ origin

BI: alters the physical size of the PICASO object stored in the working area

TU: turns, relative to the XYZ axes, a PICASO object stored in the working area

SH: shifts a PICASO object stored in the working area in either the X or Y or Z direction

MO: enables a PICASO object stored in the working area to be modified by a factor in either the X, Y, or Z dimension

JO: joins a PICASO object in the working area to another PICASO object in the saved area

PJ: joins a PICASO object in the protected area to the saved area

SA: saves a PICASO object in the working area to the saved area for possible output

Checking memory

CH: displays the current storage requirement of the PICASO object in the working area

SC: displays the current storage requirement of the PICASO object in the saved area

SP: displays the current storage requirement of the PICASO object in the protected area

Drawing operations

DR: draws a perspective view of the PICASO object in the working area

DS: draws a perspective view of the PICASO object in the saved area

PD: draws a perspective view of the PICASO object in the protected area

NOTE: the eye position may need to be altered before drawing using the above commands

OD: draws an orthographic view of a PICASO object in the working area

OS: draws an orthographic view of a PICASO object in the saved area

OP: draws an orthographic view of a PICASO object in the protected area

NOTE: the above three operations require the user to specify the viewing angles

TH: draws three orthographic views of a PICASO object in the working area

ST: draws three orthographic views of a PICASO object in the saved area

CL: clears the VDU screen

EY: allows for the eyepoint to be changed

PL: allows the picture plane position to be changed

ZI: increases the size of the drawing by a factor of 2

ZO: decreases the size of the drawing by a factor of 1/2

(ZI and ZO enable the user to zoom in or out)

Note

HE: Displays a help screen to remind the user of the function of the above commands

+ End of information on OPTIONS +

APPENDIX 6

SUBROUTINE REFERENCE SHEETS

NAME TITLE2

FUNCTION Plots identification of a pupil's project automatically by READing a disc data file.

CATEGORY Text drawing command

ARGUMENTS (XFRAME, YFRAME)

XFRAME (REAL array) half the width of the current FRAME
YFRAME (REAL array) half the height of the current FRAME

EXAMPLE CALL TITLE2(14.85,21.0)

This statement displays a request to input the name of a datafile of the form that has a "TXT" suffix, this type of data file is automatically produced by OBJECTSYN1. The information which is plotted is identical to that plotted by TITLE1. The plot is A3 size

NAME TITLE1

FUNCTION Plots identification of a pupil's project

CATEGORY Text drawing command

ARGUMENTS (XFRAME, YFRAME)

XFRAME (REAL) half the width of the current FRAME
YFRAME (REAL) half the height of the current FRAME

EXAMPLE CALL TITLE1(10.5,14.85)

This statement displays a request to input: the name of the department, the title, the designer's name, tutor group, the date the design was created, the type of drawing, and the date of the plot. The plot is A4 size.

NOTE 1. Heading for each of the entered items above are plotted.

NAME XYZAXE

FUNCTION Generates 3-D axes X,Y,Z relative to a specific PICASO object. The shape of the axes and arrowheads is set to square prisms and pyramids respectiveley.

CATEGORY 3-D object library

ARGUMENTS (SOLID, EXTRA, AXES, TEMP,TEMP2)

SOLID (REAL array) holds an object
EXTRA (REAL) the amount between the end of the arrow and the axes
AXES (REAL array) holds the 3-D axes
TEMP (REAL array) work array
TEMP2 (REAL array) work array

EXAMPLE CALL XYZAXE(A,2.0,AXES,TEMP,TEMP2)

This statement generates 3-D axes relative to the object stored in array A. The axes are 2.0 units longer than the object.

NOTES 1. This SUBROUTINE CALL's SUBROUTINE AXIS
2. AXES needs to be dimensioned 510

NAME OPTCON

FUNCTION Enables text to be plotted from STRINGLIB interactively

CATEGORY Text drawing command

ARGUMENTS (XMIN, YMIN)

XMIN (REAL) minimum x coordinate of FRAME
YMIN (REAL) minimum y coordinate of FRAME

EXAMPLE CALL OPTCON (0.0,0.0)

This statement enables text to be plotted relative to the current origin which is at the bottom left-hand corner of the FRAME. The txt variables include: the height of the letters, the ratio of width to height of the letters, and the style of letters. In addition other text can be plotted on a new line, a base line length has to be set first. Text can also be plotted in another position. The interactive routine is supported by HELPTX, which displays information about the various commands and the current values of the parameters.

NAME OPTLET

FUNCTION Enables text to be plotted from STRINGLIB interactively.

CATEGORY Text drawing commands

ARGUMENTS (XMIN, YMIN)

XMIN (REAL) minimum x coordinate of FRAME
YMIN (REAL) minimum y coordinate of FRAME

EXAMPLE CALL OPTLET(0.0,0.0)

This statement enables text to be plotted relative to the current origin which is at the bottom left-hand corner of the FRAME. The text variables include: the height of the characters, the ratio of width to height, and the style of letters.

NOTES 1. This subroutine only plots one line of text. If the user wishes to continue to plot text another routine OPTCON may be CALLed.

NAME FACET

FUNCTION Generates a surface

CATEGORY 3-D library

ARGUMENTS (TEMP, BUFFER)

TEMP (REAL, array) work array
BUFFER (REAL, array) stores the surface(s)

EXAMPLE CALL FACET(A, CRAFT)

This statement READ's the number of surfaces to be generated from a disc file, and the XYZ coordinates which describe each surface. The surfaces are generated and joined to array CRAFT.

NOTES 1. Each record in the disc file contains the same information as PICASO SUBROUTINE IN3D, but data for FACET may cooexist with data for other SEE3D SUBROUTINES.

NAME THINCY

FUNCTION Generates a thin cylinder, which may be used as a 3-D line.

CATEGORY 3-D Library

ARGUMENTS (ALINE, TEMP, ARRAY)

ALINE	(REAL array)	stores a generated thin cylinder
TEMP	(REAL array)	work array
ARRAY	(REAL array)	stores several thin cylinders

EXAMPLE CALL THINCY (A,B,LINES)

This statement opens a disc file and initially READ's the number of thin cylinders to be generated, the number of sides of the cylinder and the thickness. Next the XYZ coordinates of the centre points of each end of the cylinders are READ and the cylinders generated.

NOTES 1. Each thin cylinder needs to be dimensioned 22*N+10, where N is the number of sides of the cylinder.

NAME	PLATE
FUNCTION	Generates a rectangular plate-like 3-D form, by making a thin cuboid.
CATEGORY	3-D Library
ARGUMENTS	(TEMP,TEMP2,BUFFER)

```
TEMP   (REAL array)   work array
TEMP2  (REAL array)   work array
BUFFER (REAL array)   stored plate(s)
```

EXAMPLE CALL PLATE(A,B,SHEETS)

This statement opens a disc file and initially READ's the number of plates to be generated. Next the direction in which the edge of the first plate faces, the thickness of the plate, the XYZ coordinates of the mid-points of each end of the facing edge of the plate to be generated. The plate is generated and data is READ for the next plate etc.

NOTES 1. As the plate is a type of cuboid both TEMP and TEMP2 need to be dimensioned 98 each and BUFFER must be large enough to hold all the generated plates.

NAME	CUTOFF
FUNCTION	Cuts a 3-D object into two pieces
CATEGORY	Object manipulation
ARGUMENTS	(OBJECT,ARRAYA,ARRAYB,ARRAYC)

OBJECT	(REAL array)	stores the 3-D object to be cut
ARRAYA	(REAL array)	stores one part of the cut object
ARRAYB	(REAL array)	stores the other part of the cut object
ARRAYC	(REAL array)	work array for closing the cut part of the object with a surface

EXAMPLE

```
CALL CUTOFF(SOLID,A,B,C)
```

This statement enables an object stored in array SOLID to be cut into two pieces. Data for defining the normal to the cutting plane and which part of the object is to be closed after cutting is READ from a data file.

NAME LNE3D

FUNCTION Generates a three-dimensional line in the form of a thin cuboid.

CATEGORY 3-D Library

ARGUMENTS (ALINE,TEMP,ARRAY)

ALINE	(REAL array)	stores a 3-D line
TEMP	(REAL array)	work array
ARRAY	(REAL array)	stores one or more 3-D lines

EXAMPLE CALL LNE3D (TEMP, TEMP2, BUFFER)

This statement opens a disk file READ's the number of 3-D lines to be generated, the thickness of the lines, and the XYZ coordinates of each end of each line. The 3-D lines are stored in BUFFER.

NOTES

1. ALINE and TEMP need to be DIMENSIONED 98.
2. ARRAY needs to be dimensioned 98 * N (the number of 3-D lines)

NAME ASSOPT

FUNCTION manipulates component parts of an assembly in various various ways before joining those parts to form a complex object.

CATEGORY Object manipulation

ARGUMENTS (TEMP,TEMP2,TEMP3,WARRAY,BUFFER)

TEMP	(REAL array)	work array
TEMP2	(REAL array)	work array
TEMP3	(REAL array)	work array
WARRAY	(REAL array)	main work array
BUFFER	(REAL array)	stores the new sub-assembly object

EXAMPLE

```
CALL ASSOPT(TEMP,TEMP2,TEMP3,WARRAY,BUFFER)
```

This statement uses data READ from SUBROUTINE ASSINF and carries out various operations on component parts generated by OBJECTSYN1 or ASSEMBLY. The new object is stored in BUFFER.

NAME ASSINF

FUNCTION READ's keywords from a 3-D data file and sets or resets variables to enable individual component parts to be assembled into a 3-D object after various operations have been carried out on the parts.

CATEGORY Object manipulation

ARGUMENTS (NASSY,NTYPE)

NASSY (INTEGER) the number of sub-assemblies forming an object
NTYPE (INTEGER) the ordinal number of the current sub-assembly

EXAMPLE CALL ASSINF(NASSY, NTYPE)

This statement READ's data from a disc file and passes the information via LABELLED COMMON to other SUBROUTINES. If individual sub-assemblies form part of a design concept NASSY and NTYPE will be incremented.

NAME BOX3D

FUNCTION Generates a 3-D frame in the shape of a cuboid. The 'edges' of the cuboid are made from small-section prisms. BOX3D is generated to suit a PICASO object.

CATEGORY 3-D library

ARGUMENTS (ARRAYA, SPACE,DIAM,NSIDES,TEMP,TEMP2,ARRAYB)

ARRAYA (REAL array) stores the object

SPACE (REAL) specifies the space between the object and the sides of the box.

DIAM (REAL) sets the diameter of the prisms which represent the edges of the cuboid

NSIDES (INTEGER) the number of sides of the prism parts, this would usually be set to 4

TEMP (REAL array) a work array

TEMP2 (REAL array) a work array

ARRAYB (REAL array) stores the "box"

EXAMPLE CALL BOX3D(A,2.0,0.1,4,TEMP,TEMP2,B)

This statement generates a box with a gap of 2 units around the object stored in array A. The boxe's sides consist of prisms which are square in cross-section and are one tenth of a unit in diameter.

NOTES
1. ARRAYB needs to be dimensioned 12*98
2. TEMP needs to be dimensioned 98
3. TEMP2 needs to be dimensioned 98

NAME AXIS

FUNCTION Generates a three-dimensional solid axis or axes with arrow heads. This routine offers the user control over all parameters.

CATEGORY 3-D library

ARGUMENTS (ARRAY,N,NPA,NPS,AXMIN,AXMAX,DIAM,HEDLGT,TEMP,TEMP2)

ARRAY (REAL array) holds the generated axis or axes

N (INTEGER) specifies either the X (1), Y (2), or Z (3), axis or all three (4).

NPA (INTEGER) allows the user to define the degree of roundness of the arrow head
NPS (INTEGER) allows the user to define the degree of roundness of the axis
AXMIN (REAL) specifies the minimum length of the axis
AXMAX (REAL) specifies the maximum length of the axis
DIAM (REAL) specifies the diameter of the axis
HEDLGT (REAL) specifies the length of the arrow head

TEMP (REAL array) work array
TEMP2 (REAL array) work array

EXAMPLE

```
CALL AXIS(SETUP,4,12,12,-15.0,15.0,0.75,1.0,B,C)
```

This statement generates XYZ axes with degree of roundness equal to a twelve sided prism (the axis) and cone (the arrow head). The axes are 15.0 units long in both the positive and negative directions, the axes are 0.75 in diameter and the arrow head is 1.0 unit long.

NOTES
1. ARRAY needs to be dimensioned N((16*NPA+6)+(22*NPS+10))
2. TEMP needs to be dimensioned 16*NPS+10
3. TEMP2 needs to be dimensioned 16*NPA+6

NAME	AXISQ
FUNCTION	Generates a square section three-dimensional solid axis or axes and square pyramid type arrow head(s) to suit.
CATEGORY	3-D LIBRARY
ARGUMENTS	(ARRAY, N, AXEMIN, AXEMAX, LENGTH)

ARRAY (REAL ARRAY) stores the generated axis or axes
N (INTEGER) specifies either the X, Y, or Z axis or all three.
AXEMIN (REAL) specifies the minimum length of the axis realative to the origin
AXEMAX (REAL) specifies the maximum length of the axis
LENGTH (REAL) specifies the length of the arrow head

EXAMPLE

```
CALL AXISQ(A, 1, 0.0, 20.0, 1.0)
```

This statement generates an X axis in array A. The axis is 20.0 units long with an arrow head 1.0 unit long. The axis starts at the origin.

NOTES

1. Since several possible combinations of axes are possible it is simpler to CALL the SUBROUTINE again for cases where two axes are required.
2. The arrow head width is one third the arrow head's length this is in accordance with BS 308
3. ARRAY needs to be dimensioned 170.

NAME FOCLPT

FUNCTION Finds the centre of a PICASO type object and returns the XYZ coordinates as a focal point for perspective drawing.

CATEGORY Object analysis

ARGUMENTS (ARRAY, XCENTR, YCENTR, ZCENTR)

ARRAY (REAL array) stores the OBJECT

XCENTR (REAL) the X coordinate of the focal point
YCENTR (REAL) the Y coordinate of the focal point
ZCENTR (REAL) the Z coordinate of the focal point

EXAMPLE CALL FOCLPT (A, XC,YC,ZC)

This statement returns the XYZ coordinates of the centre of the object stored in array A.

NAME LNDOPT

FUNCTION Enbles the user to select the orientation of the plot in either the portrait or the landscape position.

CATEGORY System command

ARGUMENTS None

EXAMPLE CALL LNDOPT

NAME METRIC

FUNCTION Enables "A" size plotting areas to be selected.

CATEGORY system command

ARGUMENTS None

EXAMPLE CALL METRIC

This statement will direct control to the METRIC SUBROUTINE which displays a request to enter the "A" size. For A4 size plots "4" should be entered, for A5 size plots "5" should be entered etc.

NOTES

1. The largest plot size is A2, because the plotter in use at Middlesex polytechnic could not plot A1 size plots in both portrait and landscape orientations
2. The smallest plot size is A8
3. If "9" is entered the user may select the scale factor, this enables scope for intermediate sizes, as well as A1 size plots where possible.

NAME SEARCH

FUNCTION searches a disc file for a data file. displays the identity of the specified data file and automatically outputs that information to disc for possible use to identify a plot.

CATEGORY Input/output

ARGUMENTS None

EXAMPLE CALL SEARCH

NOTES

1. The data file must be given a library filename as the first line of the file.
2. The library filename and data file names must not exceed 6 characters.
3. The data file identification details are read to a disc file consisting of the suffix "TXT" the three remaining characters correspond to the data file's 4,5,6 characters.
4. The "TXT" makes it simpler to delete unwanted data file name files after work has been completed.

NAME OSCALE

FUNCTION scales a PICASO type object so that it can be viewed as an orthographic projection relative to the current value of the picture frame. The scaled object is ten percent smaller than the frame either in width or height (to ensure that the view will be drawn).

CATEGORY OBJECT manipulation

ARGUMENTS (ARRAY)

ARRAY (REAL array) stores a copy of the object

EXAMPLE CALL OSCALE (HOUSE)

This statement scales a PICASO object stored in array "HOUSE" to suite the current me.

NAME CHEKDW

FUNCTION Draws a perspective view of a PICASO object and two orthographic views of the object. The views are arranged within a metric "A" size landscape oriented plotting area.

CATEGORY object drawing command

ARGUMENTS (BUFFER, FACT, WARRAY, SARRAY)

BUFFER (REAL array) stores a copy of the object

FACT (REAL) is the metric drawing factor, set to 1.0 for A4 size plots.

WARRAY (REAL array) is a work array
SARRAY (REAL array) is a work array which stores a copy of the spatial configuration equivalent to a two-view type 3-D model

EXAMPLE CALL CHEKDW (SOLID, 2.0, TEMP, MODEL)

This statement draws the PICASO object stored in SOLID within an A3 size frame and returns a 3D type model for further use if required in MODEL.

NOTES

1. WARRAY needs to be dimensioned the same as BUFFER
2. SARRAY needs to be dimensioned twice the size of BUFFER.
3. it is not necessary to set EYE and other PICASO system variables.

NAME PLANES

FUNCTION Generates XYZ coordinate planes as rectangular frames, the sides of each frame are made from very small section cuboids 0.01 square

CATEGORY 3-D library

ARGUMENTS (ARRAY,XPLANE,YPLANE,ZPLANE,SPACE,TEMP,PART)

ARRAY (REAL array) stores a PICASO object

XPLANE (REAL array) stores a YZ coordinate plane frame
YPLANE (REAL array) stores a XZ coordinate plane frame
ZPLANE (REAL array) stores a XY coordinate plane frame

SPACE (REAL) is the size of the distance between the object and the frame

TEMP (REAL array) temporary storage
PART (REAL array) temporary storage

EXAMPLE

```
CALL PLANES (CRAFT,XP,YP,ZP,15.0,TEMP1,TEMP2)
```

This statement generates three frames 15.0 units away from the object CRAFT.

NOTES

1. XPLANE, YPLANE, & ZPLANE need to be dimensioned 383 each.
2. TEMP & PART need to be dimensioned 98 each.
3. The object may be positioned anywhere relative to the main coordinate axes.