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**AN INVESTIGATION INTO 3-DIMENSIONAL
GARMENT PATTERN DESIGN**

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A thesis submitted in partial fulfilment of the
requirements of The Nottingham Trent University
for the degree of Doctor of Philosophy

September 1998

Dedication to

my dearest mum and family

and

my dear father and brother in the paradise

Acknowledgments

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Abstract

The 3D pattern design system (3D-PDS) has been available for the garment industry since the late eighties, but its ability to produce patterns for production use was questionable. An investigation into its limitations and potentials was made in order that future progression could be made.

The early investigation showed that 3D-PDS employed many novel disciplinary languages which would not be understood by a garment designer or pattern cutter. A mutual communication path was seen as vital for later work. The core problem was that there was inevitable electronic pattern distortions between 3D and 2D patterns, but there has been lack of a methodological process to investigate this problem.

The experiments were set up to find a solution by using manual pattern making expertise. A 3D 'solid' garment form was created manually, then was digitised using a 3D digitiser. Later, 3D-2D manual toiling expertise was used to obtain a pattern which was 'contact-fit' to the created 3D solid garment form. By developing a garment form in the real and virtual worlds, the comparison between the electronically and manually flattened patterns could be made, so that the problems of electronic pattern distortion could be identified. This investigation process was, for the very first time, based on assessing and evaluating the limitations and the potential advantages of modern 3D technology in juxtaposition with garment pattern cutting expertise.

This research found that major limitations of current 3D-PDS were: the impossibility of providing size and measurements for the digitised 3D garment stand data; the inadequacy of landmarks and grain used; the difficulty of obtaining a 3D block; the unavailability of a means of validating the pattern; finally, a pattern with quality fit could be produced only when the pattern was constructed in a precise dual bending area.

This study has provided a crucial step by which electronically flattened patterns could be investigated in practice in the real world. The accomplishment of this major step has contributed opportunities for a mutual understanding between the 3D technology industry and the garment industry for future progression to be made together.

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1 INTRODUCTION

1.1 Background

In the mass clothing industry, the demand for new styles requires designers to develop new patterns. Most pattern development is done by adapting existing 'two-dimensional' (2D) basic blocks because of the speed, methodological approach and means of control. This research believes that additional opportunities would be offered to garment designers if the above advantages could be integrated into 'three-dimensional' (3D) pattern cutting on the garment stand. However, this method cannot cope with two major concerns, i.e. costing and timing, in mass garments production.

3D computer aided design (3D-CAD) technologies have been attempting this for over 20 years, but the clothing industry has not taken full advantage of them. This could be because these technologies are currently inefficient for practical applications in garment pattern design, or because software companies have not demonstrated or been aware of the full potential of their systems. One of the interesting findings was that the evidence provided by software programmers or suppliers tended to address software features rather than to clarify the actual results in terms of its use in the adaptation of garment patterns. This technology was meant to be a cutting expert system, i.e. to assist garment designers in obtaining good quality patterns through an electronically flattening process, this research questioned why there was little evidence to prove its viable application for designers and cutters.

This research believed that it would be of great value if electronic pattern flattening could be evaluated in terms of garment design and electronically flattened patterns could be investigated in terms of pattern cutting expertise. By doing this, the results would be more usable for future applications or improvements by garment design and pattern cutting professions.

Unpublished documents and direct contacts¹ indicate that garment retailers may have investigated or may be interested in finding out the limitations and potential advantages of using a 3D-PDS, but there was almost no commercial demand from the garment industry when this study took place. Is it because 3D-PDS cannot cope with the demands of the garment industry or because of the lack of mutual communication between the garment industry and modern technology? While 3D-PDS has proved its success in the automotive industry (e.g. Rover and Callow Maddox car seating), why has the garment industry appeared to have ignored this technology?

In 3D garment pattern design systems (3D-PDS), first, the simulated garment form surface (i.e. fabric) has to be flattened to provide 2D garment patterns, and second, the 2D garment patterns have to simulate the *sewn* garment form and then drape it naturally on a garment stand. One of the core problems has been identified² as the limitation of flattening fabric from 3D to 2D using mathematical computerisation alone. Practical examples of this limitation have not been made clear to garment designers and pattern cutters, even though they are the very people who finally give approval to electronically flattened patterns. The researcher, who usually constructs patterns in three dimensions (i.e. modelling on a garment stand), decided to examine these issues from a designer's and a pattern cutter's perspective.

This research argues that garment pattern expertise will be crucial in the exploration of this limitation. Therefore, it was found vital to investigate historical and current manual pattern construction methods in industry and to evaluate 3D electronic garment pattern making. Importantly, the foundation knowledge of a 3D-PDS needs to be interpreted in a clear way to garment designers and pattern cutters. A vital key to demonstrate this 3D modern technology to its potential users is that the interpretation and applications need to be based within a garment environment.

¹ Direct contacts were with: Dr. Li (who was involved in investigating a leading 3D-PDS for one of the major garment retailers in the UK, dated 1995-8); London (technical manager at the S. R. Gent International, dated 1996); Huang (manager of Merry Max bridal wear company in Taiwan, 1997); and Young (senior technical applications specialist in CDI, a leading 3D software supplier, based in USA, dated Sept. 1998).

² By Heisey et al., 1988; Okabe et al., 1992 (see section 3.4.3, p.3-70).

The imprecise use of terms, such as garment design and garment pattern cutting, is a problem in the mass clothing industry. Are these two work processes identical? In current industrial practice, particularly in larger manufacturers, these two processes are often separated, but attempts are made in current 3D-PDS to merge these two processes. There is also inconsistency in the use of the term 'fit'. Its application either as a system or as a judgement is individual to each company or designer, particularly, in the context of the construction of close fitting garments. It was decided that an analysis of pattern making methods was needed and a clear model of the use of the term 'fit' would have to be constructed before an analysis of 3D-PDS was made.

Mathematical computerisation requires definite data or consistent formulations in order to provide a reliable systematic solution, whereas garment pattern construction is usually developed in conjunction with variables, for example, different body forms, various fabric properties, individual use of the term garment 'fit', and the ease factor which makes the inconsistent pattern change unclear. This diverse combination embedded within manual garment pattern construction was one of the major problems to be solved while attempting a comparison of manual pattern and electronic pattern cutting. It was seen as illuminating if the outcomes (i.e. patterns) of a 3D-PDS could be *assessed* and *compared* using manual pattern cutting expertise.

Prior to a comparison being made, an objective method of controlling the variables of manual pattern construction in order to establish a comparatively consistent condition between the real (i.e. manual) and virtual (i.e. electronic) worlds is needed. Having set up this condition, the hypothesis can then be offered as follows.

1.2 Hypothesis

If all variables are controlled in a comparatively consistent condition (between the real and virtual worlds), 3D electronically flattened patterns ought to show an equivalent quality fit in the pattern edge measurements and shapes when compared to manually toiled patterns.

In the perspective of garment pattern cutting expertise, if this relationship is to be positive, then this study demonstrates that current 3D-PDS could be efficient to use for garment patterns; if it is shown to be negative, then the experimental results from this study should provide evidence to clarify and cope with the electronic pattern deficiency when complying with controlled conditions. This relationship is a necessary intermediate phase prior to obtaining consistent patterns in a future garment 3D-PDS.

1.3 Aims

The three aims of this study are identified as follows. First, it is to investigate the garment CAD software available and its viability from a garment designer's and pattern cutter's perspective in order to share knowledge to establish its potential application in some areas of practice. Second, from this specific perspective, it is to provide evidence for the viability of the garment pattern shapes when electronically flattened and to make an analysis in a way that will make sense to garment designers and pattern cutters. Specification of the deficiencies, limitations, and potential of the current 3D-PDS can then be addressed fully for use in an apparel environment. Finally, using this approach to propose further improvements for a future 3D-PDS to meet the demands of garment design and pattern cutting.

Above all, it is to make explicit to garment designers and pattern cutters the modern technologies available in the mass garment industry, as well as to identify comparatively the fundamental knowledge of garment pattern cutting expertise for the developers in the garment modern technologies. More fundamentally, this study is convinced that one of the greatest features for both disciplines (i.e. garment making and CAD technology) can take place only when a mutual understanding and communication between both sides of disciplinary knowledge is built up.

1.4 Objectives

In order to carry out this investigation, the fundamental requirements for achieving the three aims (as stated above) need to be identified. Primarily, historical and current methods of pattern cutting expertise will be investigated for possible indicators for potential applications in 3D-PDS. On account of the applications of these methods in a computerised environment, the unclear definition of assessing the process of garment fit and its variability will need a model to provide clear specifications.

Then, the advantages and disadvantages of the 3D CAD systems available will be investigated specifically for garment design and pattern cutting. The selection of an effective system for experimental use will also be needed. For practical experiments, a process to investigate the electronic flattening and the flattened patterns needs to be devised. This will require a link between 3D and 2D CAD systems, so that full advantage of modern technologies can be taken.

Finally, it is to state specifically, from a garment and pattern designer's viewpoint, a new approach to the way that CAD technologies should be made available in future.

1.5 Mode of Study

Although this study required many different research techniques to achieve its aims, it began primarily with action research. It was a designer's investigation into current technology and was a singular case study of a designer's practical experience of using 3D CAD garment technology. It not only investigated the deficiencies and problems of the modern technologies available for the garment industry, but also evaluated the existing problems and searched for an alternative method of improving the situation in a practical way, by the analysis of the human factors in manual pattern cutting expertise in practice. It identified a particular problem and proposed a solution that could be tested empirically. The hypothesis, stated in section 1.2, was tested empirically through practical experiments

which sought to quantify the mathematical limitations of flattening 3D to 2D patterns in garment pattern CAD technology.

To carry out this investigation, industrial visits to major clothing companies were seen as essential in order that general problems could be identified in specifics. Leading-edge CAD systems which are used in the other relevant design industries, e.g. automotive, shoes, and furniture design, were overviewed and the most suitable system selected for later experiments. Importantly, links were built with relevant practitioners and research groups, so that problems and potentials of system applications were addressed in an integrated way. The scope of the investigation was limited to a women's upper bodice because, in the early stage of the development of 3D modern technologies, it was deemed necessary to focus on only one specific area and women's upper bodice garment patterns include many important features of garment pattern cutting expertise.

1.6 Research Structure

Besides an overall introduction and a concluding chapter, this thesis is primarily divided into five chapters corresponding to the research stages. Each chapter used its own methodology in order to achieve its aims. A clear structure is demonstrated in Figure 1.1.

Chapter One introduced an overall review of study. It consisted of background study, hypothesis, aims, objectives, mode of study, methodology development of this research, and the correlation of each chapter.

Manual garment pattern expertise was analysed and compared in Chapter Two. A historical survey was made to probe the origin of systematic pattern construction, and current block constructions were also compared and contrasted. Deficiencies of current block construction were analysed through the industrial practice of two clothing companies. A consistent communication between garment designers and pattern cutters was established using a clear model to interpret the term 'fit' in practice. Finally, the four

An Investigation into 3-Dimensional Garment Pattern Design

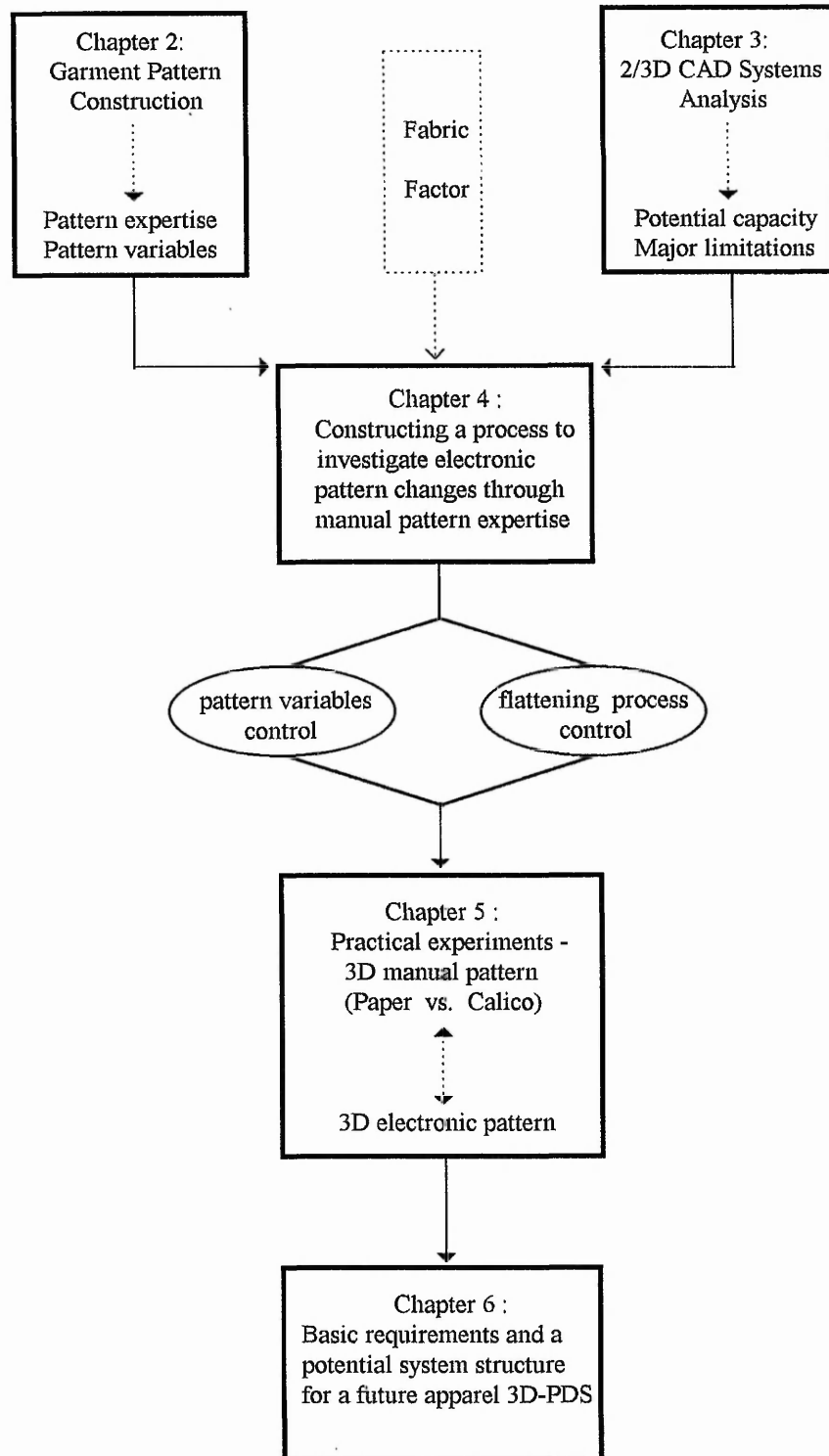


Figure 1.1 The methodology development of this study

Note : The elements in bold boxes are investigated in Chapter Two to Six; and the 'fabric factor' in the dotted box is excluded from discussion by fixing on a selected calico to eliminate this variable.

foundations (i.e. *body, size, block, and fit*), cutting women's garments in the mass garment industry, were provided. This referred to the potential variables which could affect garment pattern construction.

Chapter Three investigated the 2D/3D CAD technologies available for the garment industry. Primarily, the CAD technologies being used in the clothing industry were clarified. Then basic system structures and components were analysed. The related techniques, such as 3D digitising and 2D system linking, were established for later practical use in this study. Potential application of 3D CAD systems available in the other relevant design industries were evaluated for their practical use in garment pattern design. Related academic research was also analysed. Interviews with the other related design industries, such as the shoe and automotive industries where 3D-PDS have been established, were conducted. However, it was found that a new approach was required in order to investigate and clarify electronic pattern flattening for the garment industry.

The structure of the hypothesis was discussed in Chapter Four. Manual garment pattern expertise was used to devise a method by which manually flattened patterns could be compared with electronically flattened patterns.

Primarily, the related pattern variables, i.e. fabric, garment stand, and 3D garment pattern construction, were identified as the basic requirements for practical use in the selected CAD system. Thus, a method of establishing a consistent foundation pattern using controlled pattern variables for one particular garment form was devised in the real world.

Finally, it was necessary to produce a manual pattern to be used in the comparative experiments with electronically flattened patterns. This was done by pieces of calico and paper patterns. This method enabled controlled experiments to take place. The fundamental requirements of controlling the related pattern variables were established in order to carry out experiments included in Chapter Five.

Having established the averaged manually flattened patterns in the real world, Chapter Five was to examine the electronic pattern design and pattern flattening process of the CDI-3D system. Four main groups of experiments were conducted for the virtual world.

The first group of experiments was to specify the basic parameters used to flatten a pattern in the system. Simple geometric 3D forms, i.e. cone and sphere, were used to show these processes. The second group of experiments flattened a realistic virtual garment form to demonstrate the accuracy of pattern edge measurements and the stability of the electronic 2D pattern shape within the system, itself. Darts and seams were the two variables evaluated. The third group of experiments were made to flatten the four foundation patterns using two different flattening processes which were provided in the system. The electronically flattened patterns were compared and contrasted with manually flattened patterns. Finally, the experiment was made to evaluate the feasibility of obtaining an electronically flattened pattern with minimum distortion using knowledge gained from previous experiments.

In Chapter Six, the first introductory section was mainly a statement which identified the origin of the knowledge and contribution of this study, as well as an instruction for the chapter, itself.

The second section was an exposition of the distilled knowledge gained from the previous studies, i.e. the historical survey of manual pattern cutting expertise, the investigation into 2D/3D CAD technologies, the devising of a process to investigate electronic patterns, and the practical experiments. The analysis of the research provides a strong base for the discussion of further investigation to begin.

From this distilled knowledge, the third section proposed the potential stages for the development of a future apparel 3D-PDS. Four potential stages were classified using the two identified variables, i.e. the fabric and garment form. They were: stabilising both variables; stabilising the fabric variable only; stabilising the garment form variable only; and finally, no limits to both variables. It must be recognised that this research was focused specifically on the first stage of development, i.e. using one stabilised particular fabric and garment form, to investigate the basic requirements for a future 3D-PDS because this was seen as fundamental to any of the further stages.

Based upon this analysis, in the fourth section, the basic requirements for the first stage of a future apparel 3D-PDS were identified as: 2D design sketching function; size, measurement, and fit specifications; 3D garment stand and 3D garment prototype; 3D pattern design in a garment environment; and pattern validation and 3D pattern alteration.

Finally, a potential system structure for the first stage of a future 3D-PDS was proposed using the basic requirements specified in the previous section, which were based mainly on exploring the limitations and taking potential advantages of the current 3D-PDS.

Chapter Seven summarised the investigation of this study and the evaluation of the new knowledge which this research has contributed. Potential areas for further research were also generated from some of the processes of this study.

2 THE FOUNDATIONS OF PATTERN CUTTING

2.1 Introduction

Many variables affect the process between garment design and production in the clothing industry. This is because that, regardless of consideration of the aesthetic appearance in respect to the market and the season or how the creative process relates to the garment, a modern garment has three main basic components: the human body, fabric and cut. There are further complications as each component can be divided into more elements, such as ergonomics, sizing, fibre, yarn, fabric construction, finishing, pattern cutting and manufacturing. These elements supplement and interact with each other.

Apparel design: the process is creative and comprises of a number of inter-relating elements, namely: the concept, materials, design engineering, pattern construction and manufacturing. (Newton, 1989).

However, this research is primarily concerned with an assessment of modern technologies that transform 3D form to 2D patterns for garments. Therefore, this chapter will focus on the basic elements of pattern cutting. The relationship between the fabric and garment form are two significant variables which determine garment patterns. Aldrich (1996) offers a statement of the importance by relating fabric to form while most of the literature on pattern cutting ignores this relationship¹.

'...complex shapes can be achieved by combining techniques and inserting the shapes at different points around the body..... When using any methods, the overriding consideration must be the effect produced by the fabric and its realisation of any creative ideas.' (Aldrich, 1996, p.63)

Whilst acknowledging the importance of the relationship between fabric and form, it is important for this research to stabilise this variable by starting with a stable fabric. Therefore, a medium weight calico² will be used in all experiments with garment blocks.

¹ Kunick (1984); Kopp, Rolfo & Zelin (1987); Shoben (1990); Cooklin (1994) and Bray (1994)...etc.

² This choice was made after general interviews with cutting practitioners (See Appendix 1).

The relationship of the human body to garment form, an understanding of garment size, garment blocks and the use of the term 'garment fit' are the basic elements of industrial pattern cutting techniques which are seen as necessary for investigation by this research.

The relationship between manufacturers and major retailers is the context within which this study is placed. The garments they supply are mass produced. Many of them are using 2D pattern design systems in parts of their production of patterns, and some have expressed their interest in using 3D CAD technology. It is important to note that some manufacturing companies that have 2D pattern design systems are still producing patterns manually. In order to understand and identify the variables and also the restrictions that exist in the mass production garment industry, two studies will be conducted in two companies supplying to major retailers³.

Fashion designers often interpret their 3D creative ideas for garments by modelling garment toiles on the stand (3D manual pattern cutting) or via 2D drawings, whereas pattern cutters cut 2D paper patterns (2D manual pattern cutting) for fabric garment samples. It was found during this study that in some companies there was a distinct division between the garment designers and the pattern cutters, and it was recognised that it could be an advantage if these two work processes were integrated.

As stated in the introductory chapter, one of the major questions posed by this research was: could these two identical work processes be brought together in the 3D electronic environment? It is therefore important to investigate the electronic and manual methods available to pattern cutters and to investigate pattern cutting in the design department of the two companies. These investigations focus on the four elements of the *human body*, *garment sizing*, the *garment blocks* and the use of the term '*garment fit*'; both in pattern cutting literature methods and on their use in industrial practice. Whilst the four elements identified are mainly discussed with reference to 2D manual pattern cutting, it must be recognised that they are also relevant to 3D pattern cutting.

³ Visits were made to Martin Emprex International who supply garments for Debenhams, Dunn, Littlewoods etc., and to Coats Viyella - Meritina who mainly supply garments for Marks & Spencer (one of the major garment retailers in the UK).

Although the value of 3D manual pattern cutting, in terms of communication between designer and pattern cutter and the opportunity for experimental design is recognised, the principal method of creating patterns in the mass clothing industry is by the adaptation of blocks which are mathematically constructed (2D manual pattern cutting). This is because it provides an effective methodological means to control the shapes of patterns and sizes and it copes with the demands of supplying niche markets which require different types of garment fit. However, 3D manual pattern cutting is usually practised by bespoke and creative designers modelling the style directly on the garment stand. This technique is sometimes used in industry to solve particular problems. It is often preferred but it is more time consuming and individualistic, and therefore less controllable.

Having taken these practical conditions into account, it was decided to identify the foundations of cutting garments in the mass clothing industry. The four factors investigated are identified as: the body, the size, the block, and the use of the term fit. A general historical background survey is made for each section. Specifically, in the first section, the four factors which are related to body variations are identified as body form, shape, posture, and proportion; in the second section, the current problems and limitations of the size surveys are analysed; in the third section, current close fitting block construction and critical analysis are investigated; in the fourth section, a classification of the nature of the term 'fit' is applied to current block construction, a model for defining the 'bodice garment fit', particularly focusing on a women's upper bodice, is established, and 6 different close fitting block constructions will be compared and contrasted regarding the term 'fit'; finally, a summary is made to show the problems with the manual method of pattern cutting, as well as to highlight potential solutions when modern technologies are employed.

2.2 The Human Body

The human 'body' is the main consideration for garment production. This can explain why a garment is also known as 'the second skin' (Horn and Gurel, 1981). Pattern cutters have to take account of 'body variations' which are crucial factors in the production of a satisfactory garment. While some manufacturers buy a basic commercial garment stand, some companies establish their own 'standard garment stands' according to their own niche market. The garment stand provides only a 'static' view of the garment and its appearance; whereas an in-house human model is used to assess the functional performance (i.e. body movement).

A garment-cutting system must necessarily be based upon the human figure, which strictly speaking, is irregular in outline and form though possessing a relative regularity between section. (Morris, 1932, p. vii)

An awareness of figure variations should alert you to the need for possible pattern alteration and garment adjustment. (Liechty, 1995, p.33)

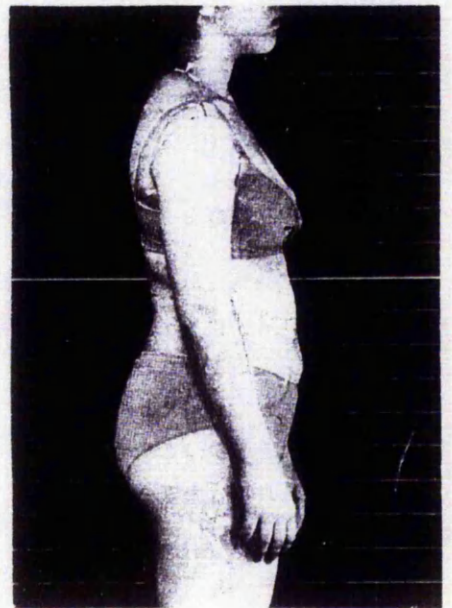
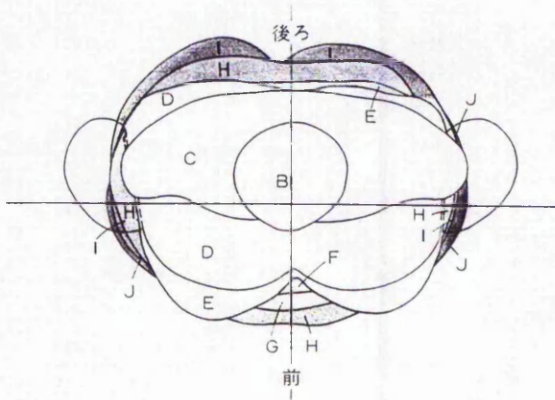
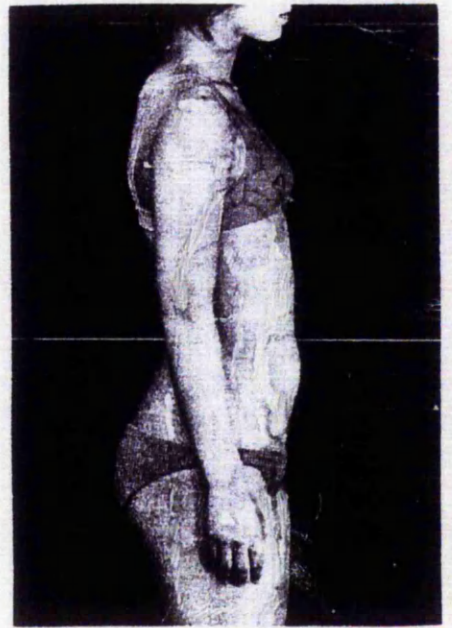
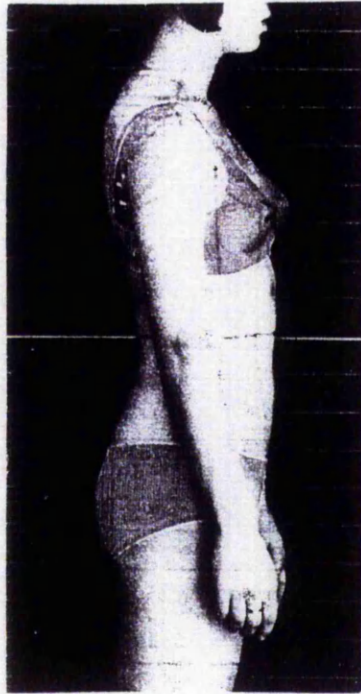
In examining the variations of body form (Figure 2.1) in detail, the side view is important because different information can be obtained. First, that which relates to horizontal areas (i.e. three control sections, shoulder, bust and hip outline) and the vertical areas, of body height, and second, the side view can be used to show the basic proportions of the body and help to identify how much suppression is needed to define the body shape. This view also gives clear evidence of variations in body posture (Figure 2.2).

2.2.1 Overview

From observations of historic garments in museum exhibitions⁴, one can easily see how the specifically constructed body changes over the years, both in stature (height) and in proportion. Garment stands are required for exhibiting a specific period of fashion (Arnold, 1973, pp.159-169).

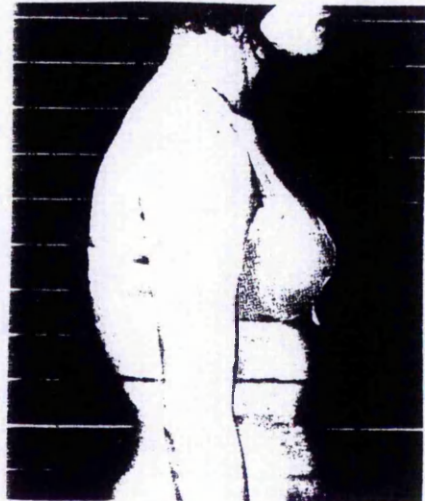
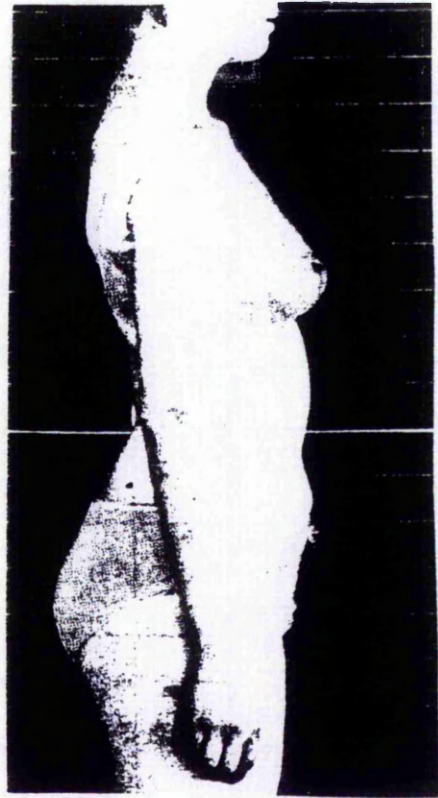
⁴ One also can see changes in the body shape over a short period. For example, a recent exhibition, 'The Cutting Edge: Fifty years of British Fashion', held in London, at the V&A Museum, Mar. - Jul., 1997.

Figure 2.1 Body variations showing body form, body shape, and body proportion



These figures were featured in 'Clothing Construction - in Theoretical Structure' (Miyoshi et al., 1994).

Figure 2.2 Body variations in posture



These figures were featured in 'Clothing Construction - in Theoretical Structure' (Miyoshi et al., 1994).

In previous times, for some women, the upper body torso was supported by the boned bodice of the gown (Bigelow, 1985, p.201). Body shapes were forced by corsetry or other structures to define the body into the fashionable shapes of the period (Figure 2.3).

The most important thing to remember is that seventeenth, eighteenth and nineteenth-century corsets forced women's figure into very different shapes from those of today. Backs were far narrower, as the shoulder blades were pressed together by whalebone. (Arnold, 1973, p.164)

From the sixteenth century until twentieth century, women's bodies have been encased in some form of structure⁵. Early in the twentieth century, Poiret (Arnold, 1973), influenced by Greek costume, produced dresses with a simplicity of cut which draped the body figure. Vincent (Arnold, 1973) cut fabric on the cross grain so that the dress clung to the natural figure shape. Although the general trend in fashion through the twentieth century has been towards the display of the natural body shape, until the 1960's corsets and 'roll ons' were worn by many women to control the waist and hip line. From this overview of the historical human body change, it was found that garment pattern cutting did not necessarily aim to fit the actual body shapes of the women, instead, it was to force it to a particular form. Today bras can still mould the bust into current fashion shapes. Learning the way women's bodies change is vital for pattern cutting, e.g. distributing suppression.

In examining the body variations, it appears there are four significant identifications to be addressed, these are: the *body form, shape, posture* and *proportion*. These four elements are mainly used to contribute to size coding and the drafting of the blocks and to assess the 'garment fit'.

2.2.2 Body Form

Female human bodies vary dramatically in form. Mass production methods ensure that garments are divided into groups (size codes). These can be narrow or more diverse, but few mass production companies are involved in made-to-measure garments⁶. The garment

⁵ For a short period at the beginning of the eighteenth century, the natural shape of the body appeared in high waisted dresses of fine cotton and muslin.

⁶ 'Creation Bridalwear' in Wigan is an example of a company involved in made-to-measure bridalwear.

Figure 2.3 The changing shape of women's bodies by construction:
a corset showing external force changes her natural body
form and shape



2.3.1



65 1900. "Spécialité" corset. The
new straight-fronted corset, white
coutil, 27s. 6d. (*Dickins and Jones*)

2.3.2



2.3.3

- 1 Picture '2.3.1' was featured in 'Patterns of Fashion' (Arnold, 1994).
- 2 Picture '2.3.2' was featured in 'Corsets and Crinolines', 2nd ed. (Waugh, 1993).
- 3 Picture '2.3.3' was featured in 'A Handbook of Costume' (Arnold, 1973).

block made for a particular group will necessarily fit precisely the body forms of only a small number within that group. The pattern aims to fit approximately the body form of as many as possible.

The hip and bust measurements are the two main criteria used to identify the form of female bodies. The selection of the control dimension through which size codes are developed is controversial and varies according to the method of calculation. This is discussed further in section 2.3. However, it is important to recognise that the shoulder dimension is another essential consideration to be taken into account. It is claimed that from the relationship of these three dimensions a basic classification of women's body forms can be generalised (Miyoshi et al., 1994, pp. 72-82; Zangrillo, 1990, p.4).

An overall observation of garment stands (Appendix 2) helps bring a general understanding about how the current 'body form' is regarded, for these garment stands are widely used by current garment manufacturers and retailers.

Clothing manufacturers and pattern companies design with a standard figure in mind. This established standard is based on the statistical average of many figures. It is often an "ideal" figure with proportions, contours, symmetry, and posture that are considered perfect. (Liechty, 1995, p.33)

Rarely can garment technologists perform a satisfactory garment fit on the stand, (i.e. *static fit*) because a live body is required to assess if the garment provides satisfactory body movement, (i.e. *dynamic fit*). A garment stand is an average body figure which does not exist in reality; therefore, it is necessarily an ineffective method for providing basic criteria for the next assessment when different live models are often used. This is a critical argument; this research claims that it would be more beneficial to provide garment stand form modification according to each niche market demand rather than to establish an ideal average garment stand. It is extremely difficult at this time to establish a standard average garment stand by manual means. This requires average measurements, and the problems associated with this are discussed in section 2.3. A further discussion of how the body form is associated with the garment stand and with the finished garment form in relation to the 'garment fit' will be addressed in section 2.5.

2.2.3 Body Posture

Posture refers to the alignment of the body parts and to the manner in which the body frame is carried. (Liechty, 1995, p.37)

There are variations⁷ in body posture, but there is a consensus about the stance of the average figure posture. This is reflected by the garment stand in a symmetrical balance. An understanding of these basic body figure differentiations is important to later garment technical applications; for instance, the determination of the shoulder and side seams and the dart distribution for the blades and bust of the upper bodice torso. The degree of the shoulder roundness may imply a wider across back width, and a narrower across chest width than the average. This may require modification of, for example, the armhole if the aesthetic shape of the garment is to be retained. The establishment of an average figure stance can provide a basis for investigating shape and body proportion.

2.2.4 Body Shape

By placing the human body forms into the groups which have been identified in the previous sections, one can see clearly that the problems of specific areas of body shaping arise. Kunick (1984, p.19) states that body 'size is not synonymous with shape. A garment can be the correct nominal size, but a misfit when tried on a customer'. The main variations of body shape are identified as follows.

2.2.4.1 Vertical contour discrepancy, such as nape-waist or bust-waist

It is worth noting that the vertical height of the body trunk must be shorter than the full length (i.e. a curve length which is vertically taken over the body contour) of the body; for instance the cervical height or crotch length. It is also important to recognise the fact that

⁷ The difference in degree of posture irregularities varies from the average body posture to erect, stooping and asymmetrical body figures (Poole, 1927, p.27; Zangrillo, 1990, p.34). It is also stated as 'upright' figure by Aldrich (1994, p.39); as 'sway back' by Kunick (1984, p.73).

measurements taken vertically from the body are often inappropriately transposed to a vertical straight line. Thus, the length of this transposed measurement will actually become shortened after the suppression has been taken off. Poole (1927, p.313) has stated that it has *deficiency* value. This claim is addressed in section 2.4.3.1 (the imperfection of the curvature and straight lines at centre front and back). Another example is the acquisition of the front waist length shown in Bunka's (Miyoshi et al., 1994) measuring. This method does not appear to be used by some cutting practitioners⁸.

2.2.4.2 Particular curves, such as the neck or armscye shape.

Body measurements do not indicate particular body shapes. Bray (1994, p.12) pointed out 'the difficulty of applying contour measurements to a flat surface' and stated that 'results are bound to be somewhat approximate, and inaccuracies have to be allowed...'. Inaccuracies appeared, in particular with the neck and armscye shapes.

The golden rule to observe in designing ladies' garments especially, but also in men's garments, is this: It is shape that matters, not size. Size is settled by the total, not by pieces. (Poole, 1927, p.319)

Examinations of basic bodice blocks in section 2.4.2 found that the major differences of shape occurred in the neck and armscye shapes. The formation of an armscye shape involves many variables, such as the determination of the shoulder point, armscye width, armscye height, the anterior armpit point (i.e. front arm pitch / hinge point) and posterior armpit point (i.e. back armpit / hinge point). An additional concern is the determination of the armscye depth level. It is important to recognise the fact that the placement of the armpit control points will determine the final shape of the garment patterns.

2.2.4.3 Making decisions about the amount of the waist suppression⁹

The governing factor for balance and fit of a garment is the correct allocation and distribution of waist suppression. (Morris, 1932, p.43)

⁸ Kunick (1984), Shoben (1990), Gebbia (Ed., 1993), Aldrich (1994), Campbell (1995). Shoben provides an armhole shape guide (i.e. a vertical contour) to help when drafting the blocks.

⁹ A change of body shape from convex to concave.

Waist suppression is one of the most significant factors used to assess the distortion and fit of a garment. The waist dimension may not be as variable as the bust or hip dimension; however, in considering the requirement for a live body¹⁰, it is worth noting that the waist girth is only acting as a guide to control the body shape. The determination of how much suppression should be taken at the waist can mainly dominate the look of the garment form appearance, this also involves an assessment of the garment fit and dart distribution.

The waist suppression is directly related to the dart distribution around the waist level. Morris (1932, p.51) asserted that 'suppression is only correct at the "bends" of the body, and not on the flat sections at the back, nor under the arm'. However, Morris only noticed the front and back suppression and ignored the side suppression (i.e. from front panel to back panel) of the body construction. He did not see the body form as a 3-dimensional view. In practice, the waist suppression takes place at the front, side and back waist so that it takes into account the 3D prominence of the bust, blades, hips and the thickness of the body. This 3D manipulation offers a profile of the body.

The problem of vertical contour discrepancy in manual measuring, the individual control of the particular curves, and the distribution of waist suppression show that body shaping needs to take place in three dimensions. Importantly, the shaping of a body to three dimensions need to take place continuously, instead of as an interrupted representation in three dimensions because shaping one area of the body would affect shape and balance of adjacent areas.

2.2.5 Body Proportion

All women are not of proportionate build, and the majority are developed more at the hip section than elsewhere. (Morris, 1932, p.34)

This proportion is taken according to a scale based on the Bust measurement. (Bray, 1994, p17)

Learning to recognise body areas that conform to the average and to create proportional balance is very important. (Liechty, 1995, p33)

¹⁰ Beazley (1996) stated that the breathing factor can affect the waist girth up to 2 cm.

There is an understanding by most of the garment practitioners that the human body has a proportional relationship. The form growth, which was claimed by Keyworth¹¹ in 1895, is the first recognition of this concept. It was an attempt to 'find the laws relating to human growth, so that it might be possible to develop a formula applicable to the whole population' (Kunick, 1984, p.3). This concept provided a fresh approach to the relationship between human body and garment construction. In current work, there is the Douty's Body Build Scale¹² theory to provide a Body Index.

Even though there may be variations in body form, diversity in body shapes and irregularities in body posture, the idea of body proportion is valuable for all methods of pattern cutting.

Proportions for the "ideal" figure are the product of a particular culture and are subject to change according to the whims of fashion within that culture. Very few individuals conform to these standards. However, standards do concern us, as they are part of the basis for sizing ready-to-wear garments and commercial patterns. (Liechty, 1995, p.34)

This study acknowledges that the human body has a basic proportional relationship. It is from this basic relationship that the mass production garment industry derives the idea of an average body figure, and bases its coding systems for sizing. This is discussed in the next section.

¹¹ Quoted from Kunick (1984, p.3).

¹² "Visual Somatometry" in *Health Related Research*, Journal of the Alabama Academy of Science, (1968) 39(1), pp. 21-34.

2.3 Size

2.3.1 Historical Background

In the middle of the nineteenth century, when ready-to-wear clothing began to be made in bulk and sold in quantity, size notation became important to the garment makers (Kunick, 1984, pp.1-15).

During the 1860s, Stockman Freres of France started producing stock-sized workroom stands based on their extensive knowledge of measurements accumulated over many years of producing papier mache stands to individuals' measurements. They adopted a size interval which became the basis of most European size systems used today. (Cooklin, 1990, p.4)

By the end of nineteenth century, most tailors made up the garments for both sexes, and took the measurements over the clothed figure¹³, not from body dimensions which necessitated the removal of outer garments. This must inevitably have limited the reliability of the body measurements during that period, but despite that, tailors, in particular Holding, had already noticed that the height and girth factors were important for a sizing system (Kunick, 1984, pp.4-5).

why?
By the end of the World War I, clothing manufacturers realised that more rational methods of pattern construction and grading were required (Cooklin, 1990, p.5). In the 1920's, there was an important shift in women's sizing. It was thought that the 'breast' measure was no longer suitable for the light clothing, and instead the 'hip' measure was used by some pattern makers as a control guide for a garment.

The hip girth is a better predictor of other body measurements than the bust, partly because the bust is not an easy measurement to take with accuracy, and because the size of the bust can so easily be altered by a change in foundation garments. It is common practice nowadays to use the hip girth rather than the bust to predict the size of the waist. (Kunick, 1984, p.8)

¹³ This can be seen from numbers of cutting books, e.g. Poole (1927, pp.16-19); Morris (1932, p.15); Vincent (1949, p.7); Women's Institute (1994, pp.8-10); Shep. Ed. (1987, p.209); Dellafera (n. d.).

In the second quarter of the twentieth century, the sizing information has been used increasingly to systemise garment construction. However, it was not until the first scientific large-scale body survey held by the USA in 1941, United Kingdom in 1951, France in 1968 and West Germany in 1970, that garment sizing for women's wear was fully developed (Kunick, 1984, pp.8-12; Cooklin, 1990, p.9).

Size in the mass production of clothing in the UK is generally associated with codes which indicate an average figure for a certain group of the population. A code contains a set of net body measurements for garment construction. For example, most British clothing manufacturers adhere to the BS 3666: 1982 size coding (Appendix 3). The net body measurements are mainly based on a logical and systematic analysis of the measurements acquired from anthropometric body measurement surveys. The BS 3666 coding system is an important guide to successful production in the UK clothing industry.

For in the wholesale trade there is more emphasis on fitting a large variety and number of figures than concentration on the perfect fitting of any one individual. (Morris, 1932, p.v)

It is better to work on an average of what is successful for the majority of figures. (Morris, 1932, p.13)

Size classification is the main element which enables the garment industry to develop garments with efficiency and accuracy. It is a guide for consistency in sizing for bulk production, and is required for factors such as styling, pattern designing, fabric quantities and making-up. A size code 'is therefore meant to imply, not that it is an exact size, but that it is nearer to that particular size than any other' (Kunick, 1984, p 12).

In the UK, the first large scale scientific anthropometric body survey, funded by the government, was held in 1951. The results were published in 1957 under the title 'Women's Measurements and Sizes'. It initiated scientific body sizing studies for women's wear in the UK. Since the 1960's, the British Standards Institution has been dedicated to establishing a body size standardisation for the establishment of the bust, waist and hip girths in relation to height. The main purpose of the British Standard was to provide clear information about sizing on labels for the consumers, and a pictogram was suggested (Appendix 4).

Three distinct periods of development were identified by Kunick (1984), 1963, 1974 and 1982 (Appendix 5). These are related to the dates of BSI size coding (see Appendix 3). It was not until the 1982 publication that definite measurement values were given with size codes.

Outside the UK, the first scientific study of women's body measurements was in the USA in 1941. This survey considered weight and 58 body measurements and the results were published in 1958, entitled 'Body Measurements for the Sizing of Women's Patterns and Apparel'.

2.3.2 Current Sizing

Sizing in the UK today is dominated by the large retailers and manufacturers who supply these companies and have to use their sizing information. Manufacturers with their own outlets or their own labels can determine their own size charts. Survey information is usually obtained by their own sizing surveys¹⁴. These surveys collect targeted information and it is not made available generally as it is seen as valuable commercial information. The surveys are usually targeted at the niche market that they supply. It is therefore important to examine the process by which sizing information is obtained, to clarify how size relates to the body and to see how it contributes to garment pattern construction.

2.3.3 Size Surveys

One of the basic problems in size surveys is that the definitions of terms relating to size, for example, size code, standard sizing can differ. Appendix 6 offers definitions of the terms used in this research.

It is important to examine how the main control measurements are identified for the sizing of female bodies. Attention also has to be taken of the reasons why females believe

¹⁴ For example, Burton group's survey in 1997; Evans' and GUS' surveys in 1996.

that their bodies are within a certain size code. Aldrich states¹⁵ that the 'bust girth' is a control measurement which influences females to believe what size they are. The reason for this identification is that most block drafting¹⁶ principally uses the bust girth measurement to determine the structure of the upper body block, and that most garments have been size coded accordingly.

Pattern cutters¹⁷ explain that the upper body is the most complex area of the body in which most body movement takes place. The block draft takes account of this and is seen by them as a satisfactory control measurement. If the bust line can be placed at an acceptable average level, then other areas of the garment can be modified to conform to the body figure. The bust level is therefore the most important area to be assessed. London¹⁸ states that hip girth is a better control measurement than bust girth to classify female bodies because its variations are less than bust variations. London's concept conforms to Kunick's statement (1984, p19).

The hip is a better control than the bust, because the latter is difficult to measure accurately and more easily affected by a change in foundation garments. Moreover, a measurement of the bust girth alone, gives no clear indication of the distribution of the sectional measurement around the bust.

Nevertheless, Kunick uses the bust measurement as the basic control measurement for developing the body block. This, however, is a *calculated* measurement from hip average. One has to be aware of this division of opinion on the control measurement that relates to the size code, and may cause confusion to the purchaser. The sets of measurements that make up Kunick's sizing system would be a division of the hip control measurement to determine the bust control measurement.

Current research regarding body surveys, undertaken by NTU's research group, Rosella (1997)¹⁹ states:

If there is only one control measurement, in terms of garment and generic survey, it would be the hip.

¹⁵ Private conversation, dated 19 May, 1997.

¹⁶ Majority of the block literature that uses bust girth as a control measurement to draft the basic block.

¹⁷ Aldrich (1997) and Roff (1997), private conversation.

¹⁸ J. London, S. R. Gent's manager, conducted surveys for Marks & Spencer (dated 30 April, 1996).

¹⁹ 'NTU' stands for the Nottingham Trent University in the UK (dated by 22 May, 1997).

Winks (1997) believes that the bust measurement should remain the principal control measurement and that the hip size should be related to the bust in a clear labelling system (e.g. using 'A, H, V' and 'S, R, L'²⁰). Winks (stated in Hunt, 1997) also acknowledges that 'it is unrealistic to expect all fashion garments of the same labelled size to have identical measurements - unless they are from the same manufacturer and of an identical style. What can be reasonably expected is that the garment will fit the labelled body'.

It is ideal if both bust and hip can be taken into account because, as Shoben (1997)²¹ emphasises, 'whichever you choose will not satisfy each other'. However, since the methods which are considered here will require that the most acute shaping of the body has to be considered and solved, the control measurement to be used therefore will be the bust. Because the establishment of size charts is derived from the results of body size surveys, the way the surveys are conducted determines the reliability of size charts. The problems and limitations of the processes of body size surveys are addressed in the next section.

2.3.3.1 Psychological effects

Although the BSI offers a size coding system, manufacturers may distort it to manipulate a psychological effect on consumers. The commonest size of the female population in 1951 (Kunick's survey) was size 14 and this appeared to still be the case in the 1980s (Marks & Spencer's survey)²². However, a clothing company may impose an enlarged measurement for its garments in order to flatter the customers. Therefore, it may be that a large proportion of the population who believe they are size 12 are in fact size 14. This is supported by some surveys by Rosella (1997) and personal research²³.

*You find women who would always claim to be a certain dress size by hip definition alone, but could be larger than they actually think they are.
(Rosella, 1997)*

²⁰ 'A, H and V' refer to the three body types 'which are grouped in according to the mean drop value (difference between hip and bust measurements); 'S, R and L' refer to 'short, regular and long' body height (Winks, 1997).

²¹ Shoben, director of London Centre for Fashion Studies, direct contact, dated 22 May, 1997.

²² Direct contact with J. London (S. R. Gent International) dated April, 1996.

²³ The author was involved in commercially confidential sizing surveys in conjunction with GUS and Evans during 1996.

2.3.3.2 The selection of the subjects and the acquisition of a size survey

The organisation and selection of the subjects for a size survey is crucial to its validity for practitioners. Full descriptions of these areas are frequently not available, but the following information should be explicit.

For large scale sizing surveys, the subjects have to reflect the spread of the general population in terms of social class, age, ethnic groups and geographical areas. Targeted sizing surveys, undertaken by companies for their niche markets, will measure groups that are related to their products in terms of life style, income, and body form (e.g. 'petite' or 'outsize'). The number of subjects in each size code group required to give a viable result must be measured and recorded. There can be a problem of finding sufficient subjects in the larger sizing groups, due to the 'reluctance' factor amongst larger women who do not wish to be measured. How the data is going to be classified into coding groups and the methods of calculation has to be explicit. A clear definition is required, ideally as photographic data, of the positions on the body where the measurements have been taken.

2.3.3.3 Equipment and measuring techniques

To establish a sizing system, it requires some necessary equipment for measuring, and most controversially, it involves the measuring methodology. Much of the funded research in the garment industry has been carried out in the field of human body measurement²⁴.

The measuring methods include two different approaches, manual and electronic. Whichever method is used, measurement discrepancy is inevitable and has to be taken into account. The causes of the measurement discrepancy are as follows.

²⁴ Such as Loughborough University's HUMAG research group (UK); Beazley at the Manchester Metropolitan University (UK); Rosella and Stafford at the Nottingham Trent University (UK); Fu at the Fu-Jen Catholic University (Taiwan); Miyoshi at the Bunka Women's University (Japan) and so on.

Placing the 'landmarks'

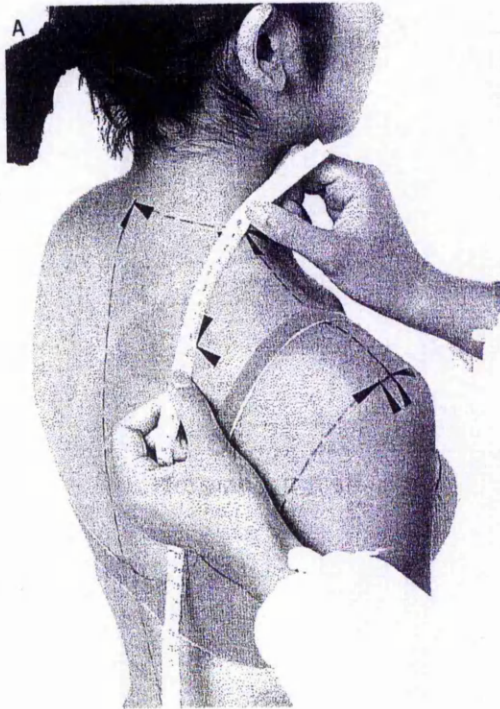
More consistent body measurements will be obtained if the body is marked either according to anthropometry or with reference to garment technology before the body measurements are taken. These marks are called *landmarks* (Figure 2.4) which are placed to help take the measurements. Where the landmark should be placed is a source of controversy, and not only differs from one measurer to another, but also from one country to another. It can also vary if a measurer measures a subject a second time.

Those who are more concerned with the garment technology, or who lack the knowledge for placing anthropometric landmarks often prefer to emphasise the garment-required measurements. They claim that their measurements are intended to suit the demands of garment construction rather than to meet the needs of medical research. In fact, the only real difference between the garment-required measurements and the anthropometric measurements is the final 'modification' of the measurements for the purpose of aesthetics, ergonomics, commerce or manufacturing. In other words, the garment-required measurements are modified to cope with the specific requirements, whereas the anthropometric measurements are intended to interpret accurately a body form construction. This implies that landmarks would affect not only body measuring, but also garment design and pattern development.

In fairness, garment technologists argue that certain measurements are not able to be taken by standard anthropometric techniques²⁵. They also argue that the anthropometric method of taking girth measurement in a strictly horizontal plane cannot give the full girth measurement required for block making (e.g. male chest and female dropped bust position). For instance, the *shoulder point* of a *garment* is realistically located 1.5~2 cm back from the posterior angle of the Acromion edge (P. Kunick, 1984, p.37) for the purpose of the balance and aesthetic look (in order to hide the shoulder seam). However, some other measurement researchers identify the shoulder point in two ways. One is located at the intersection between the Acromion and the armscye line in terms of an anthropometric measurements, and the other is located at the prominent point at the

²⁵ for example, the neck and armscye measurements.

Figure 2.4 The landmarks



This figure was featured in 'Clothing Construction - in Theoretical Structure' (Miyoshi et al., 1994).

Acromion in terms of garment-required measurements. Both points exist 1.5~2 cm from each other (Miyoshi et al., 1994, pp.46~51; 'GUS' survey, 1996).

It is generally agreed that the precise placement of the landmarks will provide and validate the body measurements. Therefore, it is important to recognise that, either for the purpose of anthropometry or garment technology, this research considers that it would be more objective and reliable to place the landmarks with respect to anthropometric viewpoint. This research claims that unless the method of acquiring body measurements can be validated and unified, the results of any sizing procedure is not valid.

Whilst it is acknowledged that expensive high resolution scanning technology will recognise landmarks, some electronic measuring technologies available, for example, the Telmat booth, cannot recognise landmarks. The 'Loughborough Anthropometric Shadow Scanner' (LASS) is a powerful 3D scanner in the UK, but it has its limitations in placing the landmarks. This system collects the 3D body data from the reflecting light without visualising the body, and at the present time it only recognises large landmarks. This will encounter the problem of accuracy because of the size of the landmark.

The acquisition of the measurement data

The inconsistency of approaches to taking the measurements often results in a significant difference in the effective tolerance allowed. For example, the armscye depth, in Kunick's, Aldrich's and Shoben's size charts, is defined for Size 12 as 19.4 cm, 20.5 cm, and 21 cm. Aldrich explained that the measurements she takes from a body are normally more concerned with a posture which is a 'natural' and 'long-time' condition. Shoben, on the other hand, explained that the measurements he uses refer to the British Standards and his empirical experience. To thoroughly understand a size chart, in particular one measured manually, one has to understand the attitudes of the measurer, and these are not always obtainable. Some common discrepancies which occur in manual or by electronic measuring methods can be identified from the following two aspects.

The first aspect is the difficulty of obtaining natural measurements. Three factors can be identified: the breathing factor which can distort this critical measurement; the 'psychological effect' often leads the subject trying to present herself as smaller than she actually is; and finally, a live body can not keep a consistent stance. The second aspect is the human error in manual measuring process. Inconsistent visual judgement is a critical factor, simply viewing the tape measure from different positions or angles can give inconsistent readings. Another significant example, the 'Harness' used by Beazley (in May 1996, Appendix 7), caused more controversy than the reliability of the measurements. This was particularly true when the Harness was not properly set at the nape point, or the tape measure had not crossed over the greatest fullness of the body contour, such as when the tape passes through the 'valley' between the buttocks.

It is generally agreed that discrepancies are inevitable whether using a manual or electronic measuring method. A comparison of the discrepancies associated with the manual and the LASS methods of measurement is made in Figure 2.5. The LASS system is specially considered because it was selected for a later 3D research project.

Apart from the LASS, several 2D/3D measuring systems²⁶ are being developed outside the UK. Although measuring equipment is still in development, the concern regarding the use and function of body data relies on the establishment of the transformation between different file formats. This will be discussed in Chapter Three.

Transposition from anthropometric data to size chart

A Table of Average Measurements and Proportions is of considerable help not only in guiding the drafting of new blocks, or as a general reference chart for checking and comparing results, but also in taking individual measurements more correctly. Bray (1994, p.7)

²⁶ For example, "Somatometry" (a method which is used to describe graphically the human body shape, originated with Douty [Journal of Alabama Academy of Science, 1968, 39(1), pp. 21-34]; the noncontact 3-dimensional human body measuring system in Japan [Bunka Women's University Research (Japanese), (1992) Vol. 23, pp. 1-17]; a computerised measuring system developed in Sweden (Textile Asia, May 1992); Cyberware; the [TC]2's scanner and "Telmat" booth measuring developed in France.

Figure 2.5 A comparison of the discrepancies in manual measuring and the LASS system

	Manual Measuring	Electronic Measuring: LASS
Measuring result	Direct body measurement data	Cartesian data of the body form
Data viability	Without the need of data transformation	Requires data transformation in order to obtain some garment-required measurements, e.g. neck or armscye.
Data reliability	More subjective and reasonably inconsistent	More objective and positive
Body posture	Unrecognised	Recognised
Psychological effect	More	Less
Landmarks	Recognised	Unrecognised (costly scanner can recognise it.)
Time factor	Time-consuming	Very time-efficient
Geographical restriction	No	Yes
Measurement obtained	Garment-required measurement	Anthropometric measurement (garment-required measurement can be obtained by manipulation.)

This statement is aimed at people who are learning to take body measurements. In size, shape and proportion, women change in accordance with their age, life style, and the current fashion trend in body figure type. This results in a complex position which leads to difficulty in effectively establishing a general body figure classification. However, regardless of how human bodies are classified, the main purpose of *coding* them is to offer clear information on labels for consumers, and to provide useful information for the mass clothing industry to produce garments more effectively. This means that the aim of general body classification is to cover the majority of the population within the size coding groups. Kunick has demonstrated how this can be done. This is shown in the Appendix 8.

The transposition into measurements within the size code can be established in a more precise form by measuring target groups, and many manufacturers have taken their surveys only to their niche market. Therefore, the secondary measurements (e.g. armscye girth, armscye depth) are consistent only in relation to the survey group, for example a younger age group or an older age group.

The main mathematical method of transposition is by the division of the raw data into percentile groups. To translate percentile groups into a practical size chart requires expertise because the data has to offer information for block construction and later grading intervals for mass production.

2.4 The Block

2.4.1 Historical Background

The earliest garment pattern²⁷ can be traced from the dark ages of Western European civilisation. The general practice to 'cut from patterns' continued from the medieval times down to the beginning of the nineteenth century. These patterns were flat shapes of the different parts of a garment (Waugh, 1994, p.34).

The first patterns of which there is any record have been traced to Italian monks who used ideas brought to Italy in the 12th century by the Greek and Jewish merchants of the day. These merchants had no doubt borrowed the ideas of various Egyptian tribes from times immemorial. The patterns were very crude, consisting merely of a back and sleeve and were made of slate, paper of course being unknown and parchment too precious to use.

As time went on, Tailoring and Dressmaking in a somewhat crude fashion began in France, until by the 14th century garments were being fitted, being long and tight at this period, and neck lines showing variations of design.

In 1671 Bensoint Boulay, a Master Tailor of Paris, offered to the public the first book on Pattern Cutting and Guide to Garment Makers that we can trace.

Until in the 18th century much grace was added to dress; the belted garment appeared. By this time patterns were definitely established and had become a necessity for all who made or had their garments made for them. (Thornton and Moulton, 1949, p.12)

The first documentation regarding the whole process of making a coat from taking measurements, selecting the closer paper pattern to stitches used (Arnold, 1973, pp.86-93) was written in 1769, by M. de Garsault. It implied that the documented paper pattern had appeared earlier than this date, even though no evidence has appeared since which can prove from where and how those paper patterns were derived. It was not until the beginning of the nineteenth century that there were shops in London which sold patterns. These patterns were sold to the professional rather than to home dressmakers (Arnold, 1973, p.121). During this period of time, the measurements and width of the material were the two main factors which were actually used to control garment pattern construction, whereas fitting was never mentioned (Waugh, 1994, p.35).

²⁷ The term 'pattern' used here should be referred to the definition in Appendix 9.

In the second quarter of the nineteenth century, the main factors which led traditional garment pattern construction into a new era were: the social aspect, the prosperity of the middle class increased so as that professional choices and outdoor activities for bourgeois women became more various and popular; the scientific aspect, Dr. Wampen's²⁸ concept of the scientific base of human body construction provided a new approach for garment practitioners; finally, the technological aspect, the invention of the sewing machine helped to produce garments more efficiently to meet the growing demand from the middle class (Arnold, 1973, pp.34-39; Waugh, 1968, p.183). Systematic garment pattern construction was therefore required for both the demands of society and the clothing industry.

In the second half of the nineteenth century, home dressmakers rapidly increased, and haute couture²⁹ and commercial pattern companies such as Butterick³⁰, McCall's³¹, Vogue, Simplicity and Burda pattern companies were also successfully developed. From 1880 onwards, pattern cutting schools appeared (Arnold, 1973, pp.3; 121-126). Garment pattern cutting then apparently divided into several strands. During the nineteenth century, different systems of garment pattern cutting continued to be published (Davis, 1994, p.1). The illustrations of the garment design together with the diagrams of the pattern construction and the description of making-up provided the information for garment design and cutting (Arnold, 1993, p.3).

It was commonly known by the cutters that women's garment cutting was originally derived from the men's garment cutting method (Thornton and Moulton, 1949, p.15; Bigelow, 1985, p.242). 'Whereas the eighteenth century was characterised by its attention to cut, the nineteenth was notable for its concentration on "fit"' (Waugh, 1994, p.112). Women's garment construction later was much more affected by style innovation and the appreciation of fit, whereas men's garment did not show much change during the

²⁸ Dr. Wampen was a Doctor in Mathematics, his first publication in England was in 1837. His initial objective in relation to the concept of the scientific base of human body construction was derived from the appreciation of the Grecian idea of beauty in sculpture (Giles, 1896, republished by Shep, 1987, pp.150-154).

²⁹ The first haute couture was established by Charles Worth in 1860.

³⁰ The first commercial garment pattern company, which was established in 1863 in Massachusetts, America, later developed branch companies in London, Paris, Berlin and Vienna (Arnold, 1973, p.4).

³¹ The first printed paper pattern was produced by McCall's in 1920 (Arnold, 1973, p.124).

century. The women's suit was first introduced by John Redfern in the late 1860's (Bigelow, 1985, pp.242-5; La Haye, 1996, p.39). This obviously divided women's garment construction into two main sections: the upper bodice and lower bodice. A demand for a close fitting the upper bodice emerged.

As time passed through the twentieth century, the term 'block pattern' appeared, defined by Holding and Hopkins as:

A block pattern is a base from which you can deviate into any style you like.

A block pattern is really a Frock coat, clerical waistcoat, or trousers pattern.

It is a pattern that must be absolutely correct in the placing of its points.

It is important in connection with these patterns to recollect that they are not cut for any excessive drawing in, stretching, or manipulation, and certainly they are not cut for big shoulder pads or stiffened fronts. (Holding, 1905, p.9)

A good set of block patterns is, then, a valuable possession amongst a cutter's set of tools. These should consist of a set of jackets, one of bodices and one of vests, cut in the single-breast style, ranging from 32 to 42 inches breast, rising every 2 inches. To do these carefully in detail, by infusing a good style in placing of seams and to be correct in every point. (Hopkins, 1990, p.4)

These statements offer a general view of how garment cutters have gradually recognised that a *block pattern* should be simplified as a base of garment construction and then used in association with style variations. This may have been the emergence of the concept of the 'basic block' in garment construction.

Continuously, from approximately 1780-1950, a number of systems of garment pattern cutting appeared. By the time of the invention of the tape³² measure, these various systems of cutting could be divided primarily into three strands, the 'Proportionate', 'Direct' and 'Sectional'.

³² 'Who it was that first introduced inch measures, there are no facts at present to prove'. However, a general agreement made for the beginning of the nineteenth century. Before this record, it was known that 'the length of King Henry I's arm was taken as the basis of our measurement. This was called a yard, it was subdivided into thirty-six parts, each part was assumed to be equal to the joint of a thumb or pounce, as the French still called an inch' (Giles, 1896, republished by Shep, 1987, pp.93-146)

2.4.1.1 The Proportionate Systems

'The origin of the art of cutting by system was unknown', and 'in the first quarter of the nineteenth century there was quite a concourse of authors and inventors of systems' (Giles, 1896, republished by Shep, 1987, pp.73-90). The Proportionate System, drafts the pattern using one constant measure to guide the rest of the other relevant measures. The breast measure is usually chosen as a control measure. Important systems are as follows.

The Old Thirds System

May be defined as the methods of cutting in which all the points producing the outline of the garment are found by certain proportions of the circumference of the chest-thus, roughly speaking, the front of scye is located at two-thirds, the depth of scye at one-half, &c., &c.' (Thornton, 1908/12, p.2)

The Old Thirds System is the oldest cutting method which has been traced. The system aimed to identify 'the comparative relations which exist between the various parts of the body, and to compare all the other parts with one of them' (Giles, 1896, republished by Shep, 1987, pp.145-8). The method first obtained a man's chest girth, and then divided that measure into half for the back length, one-third for the scye, one-fourth for the side of the body and one-sixth for the back. It also fixed two inches and one-quarter for the waist suppression at side.

The Minister System

The 'Minister System' is the first documented cutting system and was published in 1820. Giles claimed that 'the most noteworthy feature of this system is the introduction of the principles of the square for drafting purposes'. This system was able to prevail because it was more methodical in its construction. 'Three entirely original principles in the art of cutting, viz., firstly, 'the use of the square for finding the balance; secondly, the plan of finding a line on which to place the back when closed at the shoulder, so as to render the shape of back entirely optional; and thirdly, the method of producing the forepart and

skirt together' (Giles, 1896, republished by Shep, 1987, pp.131-4). Eventually the Minister System was replaced 'by divisions of a scale proportionate to the front of scye measure' (Giles, 1896, republished by Shep, 1987, p.133) because inaccuracies were caused when drafting coats for corpulent men.

Morris's System

Primarily, 'Morris's System' was also based on the breast measure. Later, it was modified using two breast measures: 'one the actual circumference of the chest, the other measure corresponding to the height of the customer' (Giles, 1896, republished by Shep, 1987, pp.175-6). Morris's System (Morris, 1932, pp.20-39) used half the bust size as his *working scale*³³. Six measures³⁴ were required in the system. It stressed the necessity for cutting the front shoulder half an inch less than the back shoulder.

The relative proportions of the height and width and deviations from the normal draft for varying figure attitudes may be calculated by scientific formulae based upon the height of the figure in conjunction with the girth factor. (Morris, 1932, p. vii)

It is generally understood that geometrical calculations are essential in a work on cutting in order to give an appearance of basing the systems on scientific foundations'. (Morris, 1932, p.vii)

Poole's System

Poole's System established its working scale using 'a quarter of the chest measure plus 7 1/2 inches' (Poole, 1927, pp.18, 407-428). He took the smallest size of a woman's bust development as a constant base, and then further developed it to a working scale. Poole's System provided two concepts: the form growth (Poole, 1927, pp.407-428) and the finding of the triangle³⁵. Poole noticed that the typical female form did not require equal proportions, therefore she did not require a coat constructed by an equal scale.

³³ It works as a 'base measure' which can be used to draft the other relevant measures accordingly.

³⁴ Including the bust, waist, waist length, full length, half-back width and normal height; the hip girth was a proportionate increase of the bust size.

³⁵ It was Poole's theory that 'Pythagoras's Theorem' could refer to a constantly triangular relationship between the neck point and the shoulder measures (Poole, 1927, pp.10, 313-319).

Consequently, Poole wanted to 'compute a scale to satisfy the typical allocation of proportions in the female figure' (Poole, 1927, pp.407-432). He also used 'Pythagoras's Theorem' to relate the neck point and the shoulder length and depth (Figure 2.6).

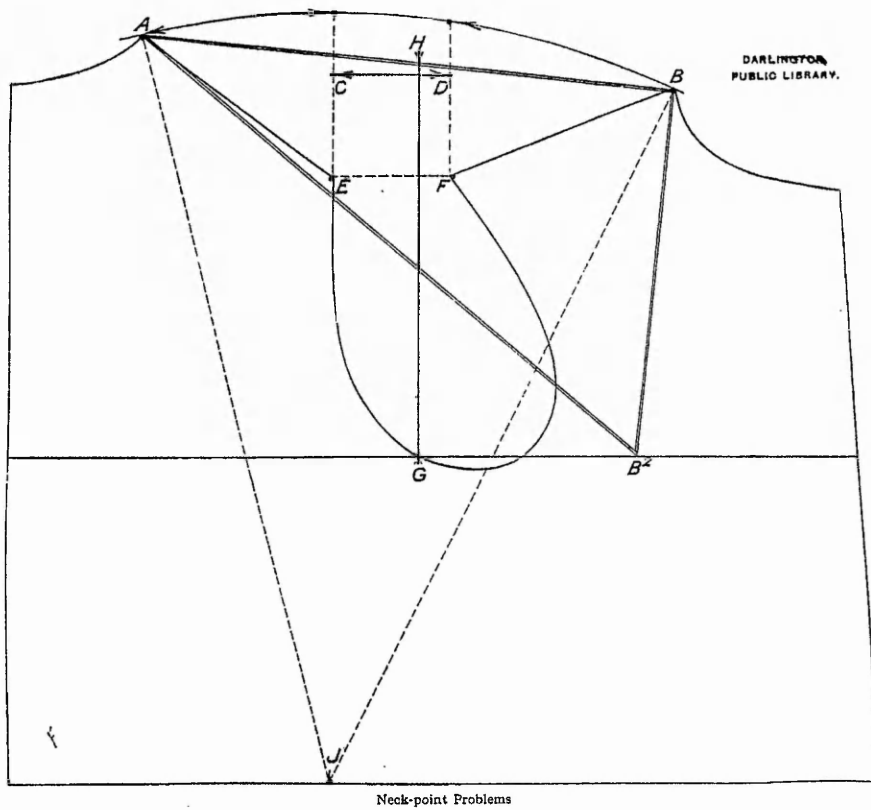
Dr. Wampen's System

Dr. Wampen's System was first published in England in 1837. He was a mathematician who was inspired from a tailor. Dr. Wampen began to dedicate himself to developing a mathematical calculating method which related the different formation of men's bodies with regard to cutting a garment. The terms, such as 'anatomy', 'anthropometry', 'mathematic' and 'scientific' became popular in the wake of Wampen's new approach (Giles, 1896, republished by Shep, 1987, pp.150-4). However, Dr. Wampen's written works were too difficult to understand and too many professional terms were used for ordinarily educated tailors to study easily.

Giles (1896, republished by Shep, 1987, p.152) stated that Dr. Wampen's principles were based upon a concept that *'every body in nature possesses the two proportions of height and width, they must be both taken with consideration in draping the human figure. Every human figure can be placed under one of these categories, i.e., first, the height proportion will be equal to the width, second, greater than the width; or third, less than the width'*. This method was claimed by Giles as an 'universally known' method, but Hopkins (1990, p.2) believed that 'no recognised authority on cutting advocates divisions of the breast measurement as the correct principle to produce garments that will be satisfactory in the result'.

The Proportionate System gradually went out of the fashion though some traditional cutters continued to use it. The reasons for this were: human bodies gradually change as time goes on, any scientific formulae of drafting which may be valuable for the time but may become inaccurate as the ideal body figure changes patterns for the average body figure; the body was measured on top of garment, any formulae developed this way would be different; working scales of proportions of the measurements may be produced.

Figure 2.6 'Pythagoras's Theorem' which was applied by Poole in drafting garment patterns



This figure was featured in 'The Science of Pattern Construction for Garment Makers' (Poole, 1927).

2.4.1.2 The Direct Systems

The principles of the Direct cutting systems were based on all the fitting measures which were taken from point to point on the body. Giles, referring to Hearn's System claimed that 'he was the founder of direct measurement systems in this country, which is proved by the publication of his direct measurement system in 1823'. Minister agreed with this claim and had published the first system of cutting, 'as we have seen also, the direct measurement system' (Giles, 1896, reprinted by Shep, 1987, p.189). Hearn stated:

*'Suppose the person to have a very short or very long neck, or if fancy requires the neck of the coat to deviate from the proportionate height, I should recommend the height of the neck to be taken: viz., by placing the end of the measure to the top of the back seam, or to the place where the top is required to be, and extend it in an oblique direction to the place where you intend the middle of the back scie to be. But to take this measure scientifically, place the end of the measure at that part of the back seam which is in a straight line with the hind seam of the sleeve, and extend it in that direction, and make a mark or dot with a piece of chalk, one eighth of the whole of the breast measure being 36 inches, the eighth of which is 4 1/2 inches, which is equal to one-eighth of half the breast measure (which is the proportionate width of the back)'.
(Giles, 1896, republished by Shep, 1987, pp.93-94)*

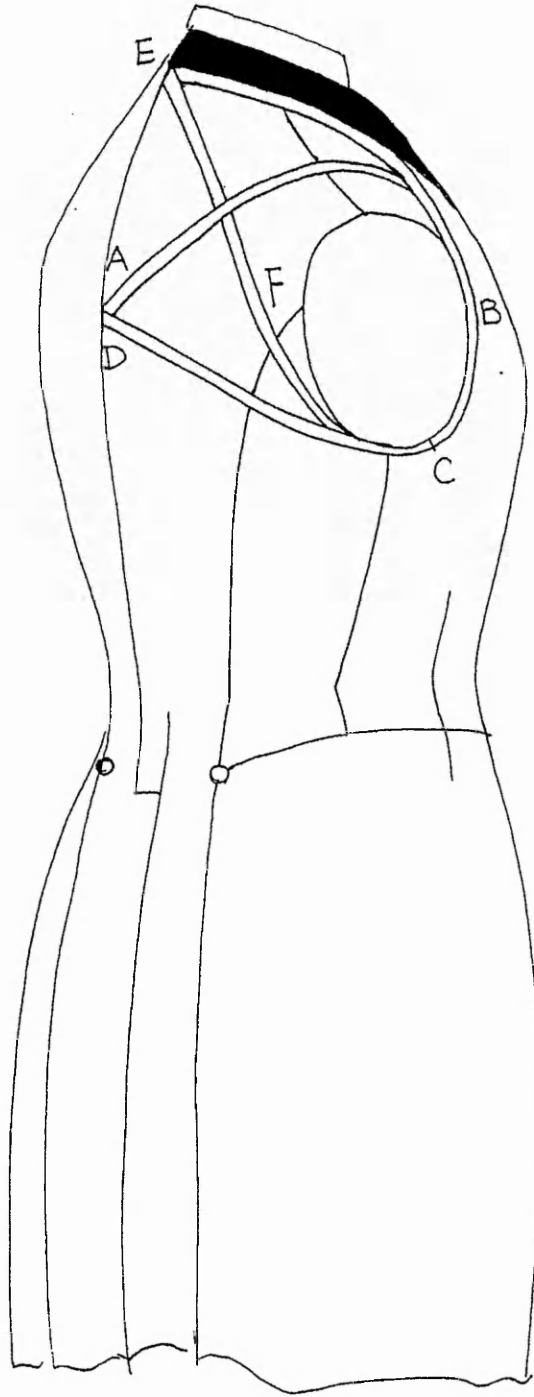
Although Direct systems used the actual measuring of figures to interpret the body which it was intended to fit, it was criticised that the method of taking the measurements was actually more determined by the accuracy of the garment construction rather than the system itself. A new system, the Sectional System, was therefore developed which aimed to deflect this criticism. Thornton and Moulton (1949) stated as that:

These defects are more pronounced than the defects mentioned in connection with the breast measurement, as in the case of making a mistake, it is to a certain extent corrected by the fact that the principal points are found by division. (Thornton and Moulton, 1949, p.14)

2.4.1.3 The Sectional Measure Systems

The first shoulder measure, based on the length of the shoulder, was taken from the nape, over the front shoulder, under the arm and then back to the nape (Figure 2.7). The difficulty in finding the depth of the bodice shoulders was realised. Hence, it was vital to

Figure 2.7 Thornton's International System: The taking of Measurements



The figure was featured in 'The International System of Garment Cutting' (Thornton, 1911).

provide other supplementary measures of the shoulder, e.g. the width of the shoulder, in order to construct any close fitting garments because 'the sizes of the shoulders vary in proportion to the breast measurement' (Hopkins, 1990, pp.3-4).

In Thornton and Moulton's System ('T & M'), certain sections of the front and back bodice were required for special consideration. They were, first, the depth of scye, waist advancement and scale from breast measurement for the back balance, and second, the slope of the shoulders, bust development and size of the waist for the front balance. The 'T & M' system recognised that using principles of men's garment cutting for ladies' garment often produced models 'too long in the back balance and too short in the front balance' (Thornton and Moulton, 1949, p.15). This was because men's backs are usually rounder than women's, whereas women's front balance are longer than men's. Therefore, there were two features provided in the system; first, 'a shorter back balance' for a women's garment 'than would be required for a man of the same breast measurement', and second, 'the reduced distance from the back to the front of scye demands a relative reduction of width' (Thornton and Moulton, 1949, pp.15-6).

It is generally understood by the cutters that there is no system which can be used as a standard system for all the garment construction. In practice, this is true, when the 'scientific body survey' became popular, and more information in relation to the body became available. This was not only the methods of taking the measurements, but also their application. Since 1951, new measuring and sizing techniques and technologies have again led garment pattern cutting into another new era.

2.4.2 Current Block Construction

Garment block construction in conjunction with viable size charts enables the mass clothing industry to target effectively their niche markets. This is often carried out by 2D garment pattern drafting and modification which are generally based on a garment technologist's empirical experience. The individual experience is usually obtained either from senior cutting experts or from personal 'trial and error'.

...during the last hundred years, it emerges that the majority of publications written, discuss the debate and illustrate methods and systems of pattern construction. It is the exception for any reference to be made to the general principles of pattern construction. Divisions are made for men's women's and children's wear. Newton (1989)

It is generally known that garment pattern making for women's wear is often different from men's or children's wear in the current clothing industry. The reasons for this difference are various; for example, types of garment, the different body profile, the different attitudes or the different 3D shape construction of the bodies all contribute. When considering different close fitting garments, although they are varied from each other, they have to fit a human body form. Therefore, the fundamental principles needed to achieve this task ought to be the same since they are all targeted at generating the 2-dimensional drafts by 'unwrapping' a 3-dimensional body form.

Companies hold empirical knowledge of garment cutting for their particular production. Individual pattern cutters may leave, but a fund of pattern knowledge usually remains in a company. It is the procedure by which this empirical knowledge of garment cutting expertise becomes a 'body of formalised knowledge' that directs specifications for blocks. 'As fashions change the ideal body size and shape also changes' (Campell, 1995, p.1). However, 'fashions change but the principles of cutting the flat pattern do not' (Bray, 1994, p.iv). Therefore, it is worth examining the main principles used by cutting experts to complete the construction for the basic block. The 'close-fitting basic bodice block' type was selected for this study for its practical applications for the future experiment in 3D pattern cutting by CAD.

There are various ways to achieve a successful garment product and the choice at the approval stage will often be affected by constant changes in the fashion environment. It is garment pattern technology that more often causes controversial arguments and requires the most modification. To reduce disagreements, satisfactory procedures³⁶ between the designer and pattern cutter should be agreed at the earliest stage of the pre-production process. This would provide a more viable environment for garment pattern technology.

³⁶ One of the problems is the confusion and the definition of the terms used within the industry, for example, in relation to the block. The use of the terms by other cutting experts are also provided in the Appendix 9 'Block, Pattern' and relevant terms used by the other garment cutting experts.

To understand the fundamental principles of block drafting, it is important for designers and pattern cutters to have a good mutual understanding so that they communicate clearly with each other. Consistency in terminology would be of great value to the industry, e.g. the term 'fit' (see section 2.5). Definitions of the terms which relate to the block are provided in Appendix 10.

This study will intend to establish some fundamental principles of close fitting garment block construction for 3D CAD cutting with regard to the body form, shape, posture and proportion which will be applicable to bulk and made-to-measure procedures. This section of the study investigates 3D and 2D manual block cutting in order to understand the basic principles which may be of assistance in later 3D CAD garment cutting.

2.4.2.1 Three-dimensional (3D) manual block construction

The empirical knowledge of close fitting garment cutting expertise is generally based on: first, modelling³⁷ on the garment stand³⁸ using it as a general reference of the body, a selected fabric (mainly calico) is used; second, manipulating the selected fabric to achieve an acceptable garment form which takes account of the requirements of a *live* human body, for example, breathing and moving, and finally, making up and trying on a live body to assess the satisfaction and viability of the garment. After continuous verification and modification, the definition of satisfactory garment fit is gradually established.

In Western countries, the block is usually modelled on the stand without ease, this is added later when it is established into a flat block pattern. The methods of modelling are divided into two main strands: *structured* and *non-structured*. The 'structured' modelling refers to the creation of a garment to *fit* the body form and the 'non-structured' modelling refers to the creation of a garment form that drapes freely around the body. This study is based on the first method, the project focuses on close fitting garments for viable application in mass production.

³⁷ Other terms for modelling, for example 'draping', 'toile' or 'moulage', are also used (Mee, J. and Purdy, M., 1987, p.1).

³⁸ This would be a 'live body' before the garment stand has been created.

Apart from a garment stand and fabric required (calico is often selected)³⁹, a basic understanding of modelling a close fitting bodice block is crucially important. It involves: marking landmarks; taping the horizontal and vertical referencing lines⁴⁰; finishing⁴¹ the calico; determining the suppression and ease required in specifications; and finally, manipulating the calico and reducing the external distortion to the minimum.

One of the most important concerns is the determination of the suppression and ease distribution at the front and back bodice and above or beneath the armseye depth line (or bust line). Garment construction in three dimensions could establish a good mutual understanding between garment designers and pattern cutters. A 3D garment form (block) can provide a good foundation for the development of an imaginative design idea because it contains a 3D garment form and the placement of the basic structural lines. It is possible that most of the disagreements about a garment form or *fit* could be eliminated where there is an available, agreed 3D garment foundation form. In the practices of two garment manufacturers (see section 2.6.3), it was found that designers often confirmed their final design on the garment stand when the 2D block was proving unsatisfactory.

3D garment form modelling provides not only the factual body form, but also the actual finished block form. Although it produces less inconsistency, it is time consuming and costly. The tacit knowledge of the body form gained by 3D block development is valuable when using 2D pattern methods for mass production.

Originally designs were made by draping fabric around a dress stand. Flat pattern cutting is now widely used by the dress trade because of its accuracy of sizing and the speed with which complicated designs can be constructed. However, one must always be conscious that the body is a form. (Aldrich, 1994, p.4)

...This method has two distinct advantages, the first being that the designer is working in three dimensions which assists a total understanding of the appearance of the finished garment. Secondly, it can allow the designer to work in factual measurements as against statistical data. (Mee, J. and Purdy, M., 1987, p.9)

³⁹ And relevantly required equipment, for example pads, tape measure, pins, marking pen...etc.

⁴⁰ This at least consists of the bust, waist and hip lines in horizontal direction, the centre front and back in vertical direction, as well as the shoulder and side bodice seams desired in the working block.

⁴¹ This includes steam-ironing the calico to ensure its grains and stability before modelling. Pulling a yarn at each 2.5 cm distance both in the straight and cross grain directions.

2.4.2.2 Two-dimensional (2D) manual block construction: a comparison of close fitting bodice blocks

The construction of a close-fitting bodice block is developed according to sizing and size charts in conjunction with the body form, shape, posture and proportion. It appears that good results can be expected only if there is consideration of all these points. It was seen as important that an analysis of the sequences of current block construction should be made in order to understand the principles that are used in the construction of close fitting bodice blocks by cutting experts. Six blocks⁴² (Figures 2.8 and 2.9) of cutting experts were compared. The most distinct contrast amongst each block is particularly shown above the bust level, for example, the neck base shape, the degree of the shoulder slope⁴³, in particular the construction for the armhole (i.e. armhole). More specific comparisons are discussed as follows.

The 'skeleton'⁴⁴ of the block

It is the 'skeleton'⁴⁵ (Figure 2.10) construction that determines how a body form will be built up. The skeletons are built from control body measurements. Each approach at constructing the skeleton of the block was different among the experts, in particular, the order of construction for each horizontal bodice sections, whereas there was a general and consistent agreement about the ease to be added into the bust girth, i.e. 5 cm for the half bodice block. The horizontal grid of the skeleton is the maximum upper bodice girth plus the ease for body movement, whereas the vertical grid is constantly taken from the net measurement of 'nape to waist'.

⁴² They are from Kunick (1984), Bunka (University, Japan) prototype (last revision in 1984), Aldrich (1994), Shoben (1980), Bray's (1994), and Stanley (1995) whose published cutting procedures are used currently in education and industry.

⁴³ However, this needs to take the bust dart distribution into account.

⁴⁴ i.e. the primary constructive lines which are used to establish the balancing relationship within blocks.

⁴⁵ The 'skeleton' refers to 'a main construction at the earlier stage of foundation block' in this study.

This skeleton consists of five elements: a rectangle (i.e. the full back length by the width in relation to a basic room for upper bodice), the bust line, the across front / back width vertical to the bust line and the bodice side seam.

Figure 2.8 Superimposing the six selected blocks along the centre back at the nape point

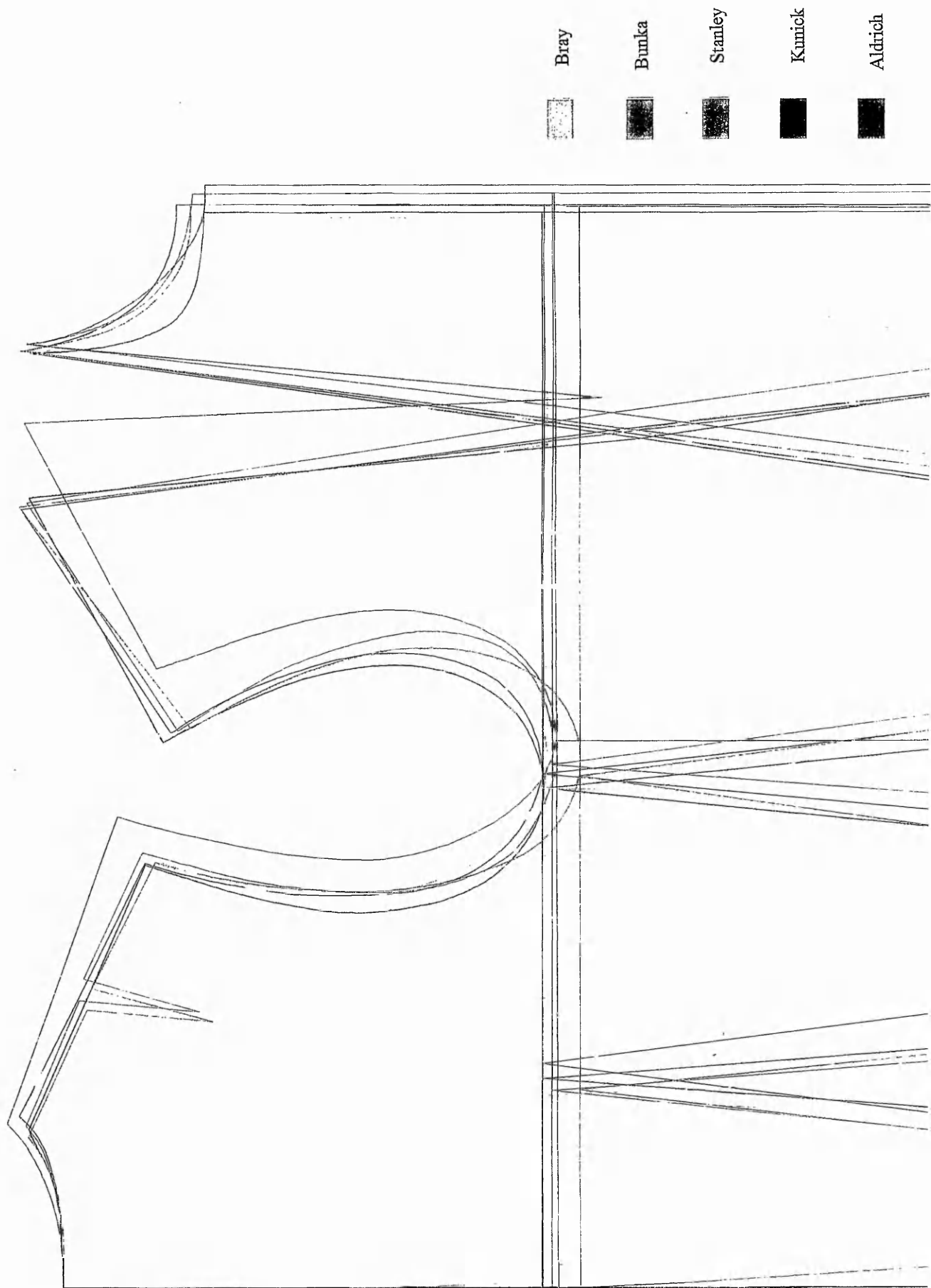


Figure 2.9 The skeleton and control measurement of basic bodice block construction

	Unit: cm					
Basic Block	Kunick (1987)	Bunka (1994)	Aldrich (1994)	Shoben (1980)	Bray (1994)	Stanley (1995)
Sample Size	12	13AT ¹	12	12	(III) ~12	12
Average Stature	164	164	160 - 170	163.5	160 - 165	164 - 169
Breadth	1/2 bust + 5	1/2 bust + 5	1/2 bust + 5	1/2 bust + 5	1/2 bust + 5	F. G. B ² .
Length	nape - waist	nape - waist	nape - waist	nape - waist	nape - waist	nape - waist
Control M ³	bust	bust	bust	bust & hip	bust & hip	bust
Key Sequences	breadth - P ⁴ = shoulder dart	1/2 breadth = side seam ⁹	breadth - R ⁵ = armscye width	breadth - X ⁶ = 1/2 Across Chest	breadth - Y ⁷ = F. P. W. ¹⁰	Central Tree ⁸
Panel width at armscye level	back + 2.1-2.3 = front	back = front	back + 2 = front	back + 3.4 = front	back + 3 = front	back + 2.5 = front

¹ It is one of Japanese body size classification, the measurements for this size is equivalent to size 12 in the UK, except the shortened centre back.

² Finished Garment Bust girth.

³ Control Measurement.

⁴ P = [(1/2 across back + 0.6) + (armscye width) + (constant for all sizes = 13)]

⁵ R = [(1/2 across back + 0.5) + (1/2 across chest + 1/2 shoulder dart)]. The shoulder dart width is 7 cm, a constant for size 12.

⁶ X = [(1/2 across back + 0.6) + (armscye width)]

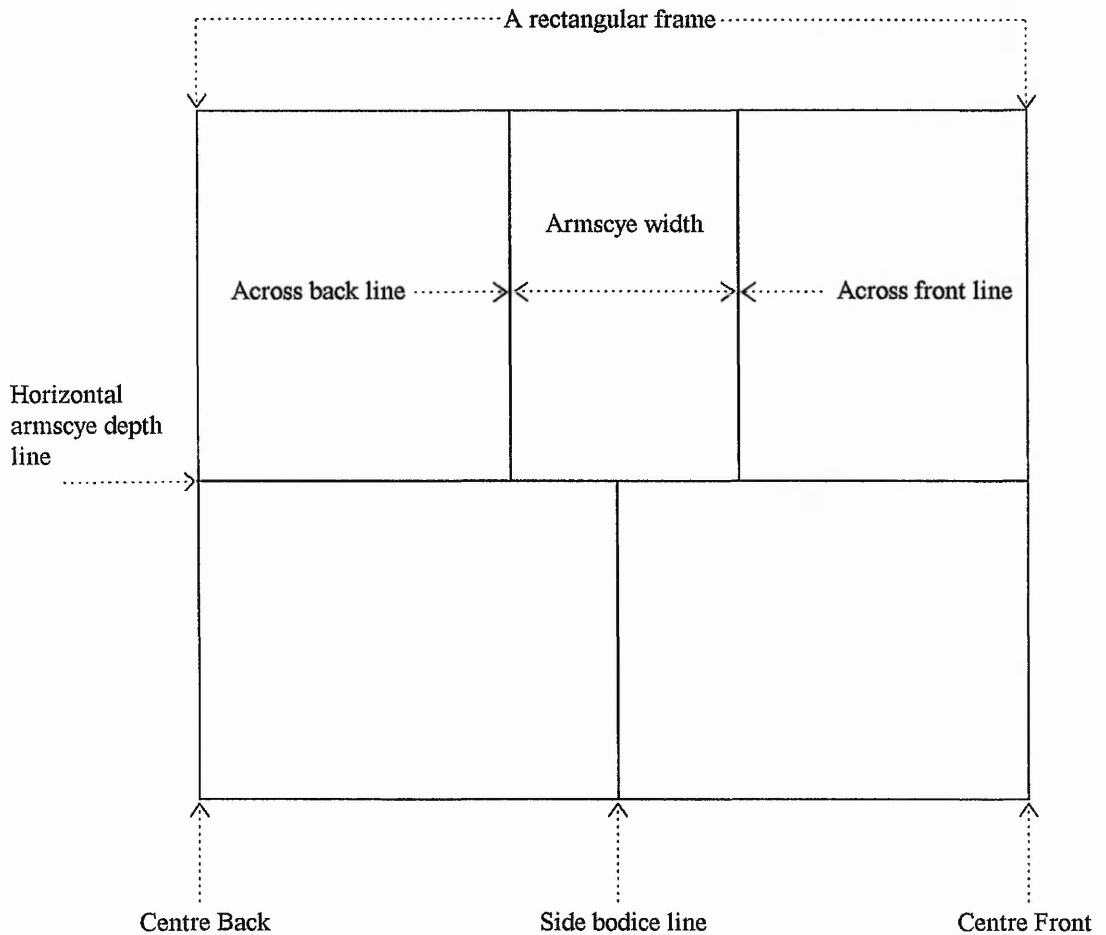
⁷ Y = [(1/2 across back + 5) + 1].

⁸ Using the position of the 'side seam' as a central line of the block, then horizontally developing out. Stanley divides armscye width into 5.2 cm (back) & 7.1 cm (front).

⁹ There are 2 cm backward at the waist level.

¹⁰ Front Panel Width at the armscye depth line.

Figure 2.10 The 'skeleton' construction which refers to a block within this study



Note: The 'skeleton' construction which is used in this study would basically consist of the elements as follows:

- 1 A rectangular frame which contains enough area for a half 'major upper bodice girth' (usually refers to breast measure) with an individual required ease.
- 2 A horizontal armscye depth line.
- 3 A vertical side bodice line.
- 4 A vertical across back width line.
- 5 A vertical across front width line.

From this comparative study, it was also found that the differences between the front and back block widths at the underarm point (Figure 2.11) were different from each other. It was noticed that five out of the six blocks used the bust girth as a control measurement to draft the block⁴⁶ (apart from Stanley's 'Central Tree' drafting theory). After drafting the skeleton of the block, the balance factor of the block constructions was considered.

The balance of the block

The balance of close fitting block construction is determined by the horizontal and vertical relationship between the front and the back blocks, and is generally controlled by the application of body measurements. The balance is controlled by three main elements: the grain line, the structural lines (Figure 2.12) and the suppression distribution.

Apart from a general agreement regarding a straight grain line at the centre front and centre back⁴⁷, there are several factors which could affect the balance of the block construction: the placement of the side neck point at the front and back blocks, the position of the bust point, and finally, the placement of the underarm point on the armscye depth. One of the most important factors to affect the balance of the block is the degree of shoulder slope. Fundamentally, this factor is determined by the placement of the front and back side neck points in association with the depths of the front and back shoulder levels. As stated, wide variations were found between the blocks (see Figure 2.8).

The suppression distribution

The distribution of the suppression is dictated by the form of the body, and ease allowance is included at the armscye depth and waist levels. A 'live body' must be taken into account, as it requires breathing and body movement.

⁴⁶ It was stated in '2.3.3 Size surveys', that although Kunick uses the bust measurement as a control measurement, this bust measurement is a calculated measurement from hip average.

⁴⁷ Bray and Stanley distribute some suppression at the centre front and centre back whilst the waist suppression is imposed.

Figure 2.11 Individual placement of the underarm point

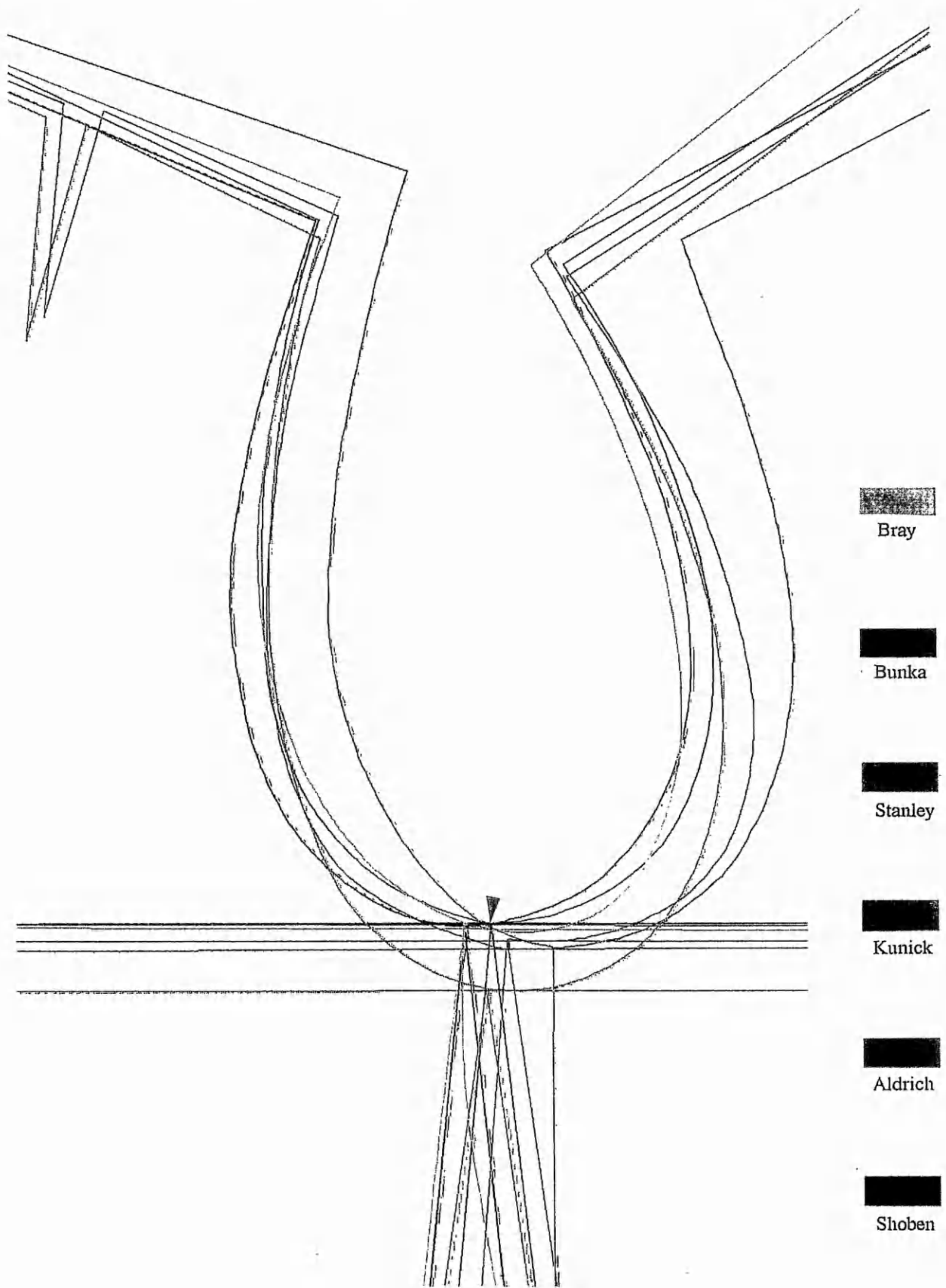
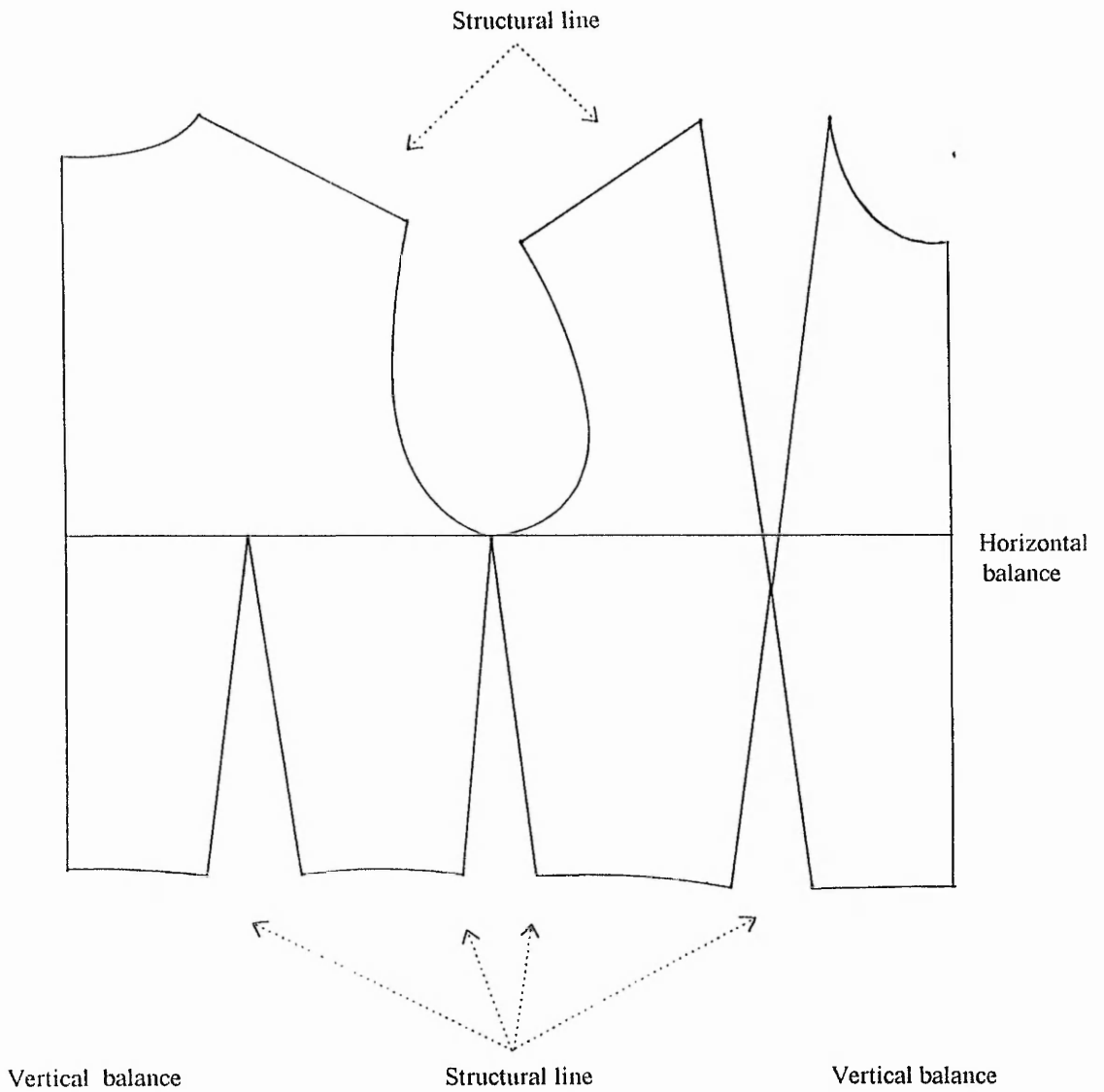


Figure 2.12

The 'structural lines' of the block construction



The 'structural lines' of the block construction refer to the lines which actually make the *finished* block (i.e. 3D block form) closely fit the body, for example, the shoulder seam, the side bodice seam, or the finished dart lines.

This figure was featured in 'Modern Sizing and Pattern Making for Women's and Children's garments' (Kunick, 1984).

The suppression generally takes place in order to create the 3D shape for prominent areas, for example, the shoulder blades and bust. Although the suppression can be distributed wherever preferred, it is commonly located at the shoulder and waist. More suppression is usually taken in the front waist dart to create a better 3D form for the bust. Individual analysis may determine the amount of suppression used, but for a close fitting bodice block (apart from Bunka prototype) the comparison does not show too significant a difference among the six selected blocks. It is worth noting that suppression also occurs at the side bodice and determines the angle of the side seam and the bust dart on an actual garment pattern is often constructed 2 cm away from the bust point in order to form the bust area smoothly. Figure 2.13 provides an overview of the suppression distribution of the bodice torso.

Care must be taken because suppression can also occur at the centre front and back. Therefore, it is not necessary for centre front and back to be straight, e.g. bridal wear. However, in mass garment production, 'straight' centre front and centre back are used more widely than 'curve' because of the manufacturing factor. Particularly, the centre front line is almost always used as a straight line for its practical use of mirroring patterns.

The construction of the neck base and armscye shapes

Unlike the shoulder blades or the bust which are prominent and apparent, the neck and armscye do not possess an objective shape or outline which can be identified. Therefore, in fairness, one can not expect to find the exact same shape from different blocks. This is particularly clear when stacking the six selected blocks along the centre back at the Nape point (see Figure 2.8). Figure 2.14 shows the inevitable variations of the armscye shape construction because of the individual placement of the armscye depth and the location of the side neck and shoulder points at the front and back block panels.

The armscye width appears to have a general consistency amongst Kunick's, Bray's, Aldrich's and Stanley's blocks, whereas each armscye shape is distinctively different due to the individual placement of the underarm and shoulder points. The major method used

Figure 2.13 The suppression distribution at the bodice torso

Suppression	Kunick	Bunka	Aldrich	Shoben	Bray	Stanley
Sample size	12	13AT	12	12	14	12
F. shoulder dart	7.2	0	7	6.5	7.5	7
B. shoulder dart	0	1.8	1	0.4 ⁴⁸	1.5	1
F. waist dart	4.5	N/A ⁴⁹	4.5	5	4 ⁵⁰	4
B. waist dart	5	N/A	3.5	3	4 ⁵¹	5.25
Side body	4	0	4	4	3.5	5
(dart sum)	(13.5)	N/A	(12)	(12)	(11.5)	(14.25)

Note 1: Placing the centre front and back seams on the straight grain were used widely by 3D toiling experts (Kunick, 1984; Mee and Purdy, 1987; Silbergberg and Shoben, 1991; Stanley, 1991) to begin a basic block toiling process; however, for even waist suppression, centre front and back lines may be shaped.

Note 2: In the example of Bunka block prototype, the suppression distribution at the upper bodice torso is not defined or indicated clearly in its constructing process.

⁴⁸ Ease-in, instead of an open dart.

⁴⁹ Not applicable. Bunka prototype's dart distribution is based on an average mathematical calculation. It eventually makes the front panel 4 cm bigger than the back panel at the waist level. This also implies its placement of the side seam.

⁵⁰ 1 cm at the centre front and 3 cm vertically below the bust

⁵¹ 2 cm at the centre back and 2 cm vertically below the half way of back line.

Figure 2.14 The algorithms for shaping the neck base and armseye shape Unit: cm

	Kunick	Bunka	Aldrich	Shoben	Bray	Stanley
B. neck width	$1/4 NG^1 - 1.6$	$1/20 BG^2 + 2.9$	$1/5 NG - 0.2$	7^3	$1/2[1/8(BG) + 2.5]$	6.7
F. neck width	$(F. neck depth) - 0.3$	$(B. neck width) - 0.2$	$1/5 NG - 0.7$	$1/6 NG + 0.2$	$= (B. neck width)$	$BNW^4 - 0.2$
B. neck depth	2	$1/3(B. neck width)$	1.5	1.5	2	1.5
F. neck depth	$1/8 NG + 2.2$	$(B. neck width) + 1$	$1/5 NG - 0.2$	7.7^5	7.5	7.5
armseye width	10.8	11.16(approx.)	11.6	11	11.5	12.3
armseye height	17.4	19.15	18	17.5^6	18.5	18.5

¹ Neck girth

² Bust girth

³ The 7 cm is a defined value (1980), the updated (1990) principle is '1/6 NG + 1.4' for jacket block.

⁴ Back Neck Width

⁵ The 7.7 cm is a defined value (1980), the updated (1990) principle is '1/6 NG + 1.6' for jacket block.

⁶ it is derived from '[1/6(AH + 2.5) + 1/4 (AH + 2.5)]'

to make these two shapes is to use an algorithm for construction. This calculation is usually based on the control measurement, such as the bust or neck base measurements. Figure 2.14 shows the algorithm which is used by individual pattern cutters when calculating the 'relative proportions'⁵². It can also be seen that these algorithms do not refer to the body proportion. They are based on a calculation which helps practitioners to draft these two shapes. By basing the calculation on body measurements, the drafts can be constructed for non-standard sizes.

2.4.2.3 Body posture and proportion in relation to block construction

Body posture, a silhouette view of the side body, cannot be identified from most current size charts, but its recognition by pattern cutters can be seen from their block construction. It is generally determined by their positioning of the front side neck point to the back side neck point which affects the length of the front and back blocks. This silhouette may be seen in a photographic facility, e.g. the Telmat measuring booth. However, a measure of 'body posture' is very difficult to obtain by traditional manual measuring methods. Because of this difficulty, this 'measurement' is not listed in the general size chart.

The earliest proportional 'form growth' theory was originated by Keyworth (Kunick, 1984); however, because fashions and bodies change over time (Campbell, 1995, p.1), this theory did not last long. Body proportion in current close fitting block construction may not be widely used in the mass clothing production as more often clothing companies have established their own blocks with *net body measurements* and *ease* imposed according to their empirical experience. However, it is useful to understand some general ideas of proportion about body construction, as it can help in the drafting of a basic block and can explain the consistency amongst some areas of the six blocks investigated. Five of the six selected blocks, (the Bunka prototype which still constructs the block using body proportions), develop their construction using direct measurements with individual empirical ease allowance added in the specific area, address this point.

⁵² A measurement by relating another significant control measurement to make it easier to be guided.

Although body proportion does not significantly appear among the five⁵³ blocks, there are still some general agreements within the block construction. For example the bust point is almost always (except Bray's block) placed at the half way point of the across front width; the armhole depth is located close to half way between the nape and waist level (except Stanley's block). However, in practice the final armhole depth often has been individually modified to cope with the requirements of a live body's movement. This manipulation often causes blocks to be distinct from each other.

2.4.3 Close Fitting Bodice Block

2D close fitting bodice block construction existed for decades. Garment cutting experts can easily identify whether and where the modification is required when different body measurements are imposed. The knowledge of drafting the close fitting bodice block from the cutting experts has been of great value, but some criticisms of the technique should be considered. From this comparative study, we are also aware of some critical areas. These criticisms may also help to explain the reason why a 3D CAD generated block cutting is proposed by this research.

2.4.3.1 The criticism

The inconsistent principles of block construction

There are two possibilities which result from the *inconsistency*⁵⁴ of constructing the block: the first is that the body measurements provided are insufficient to be applied; and the second is that the application of the body measurements or drafting method could incur a significant variation⁵⁵. Therefore, it is worth noting that each individual block construction is viable only when body measurements are derived from the same source.

⁵³ Bunka prototype is exclusive in the following comparison due to the body height being inconsistent to the other five blocks.

⁵⁴ This refers to the difficulty of using other measurements than those accompanying the block instructions.

⁵⁵ Evidence regarding Aldrich's and Shoben's basic jacket blocks has satisfied this claim.

This addresses the importance of understanding how the body measurements are obtained. The application of a misunderstood size chart can cause a significant distortion to the block construction.

The imperfection of the curvature and straight lines at centre front and back

It can be seen that the position of the centre back measurement is a vertical line located at the groove between blades. It is often shorter than the 'full length'⁵⁶ should be. For example, one can find that a 2 cm slanting inward (in Bray's block) at the waist level could cause slightly more than 0.2 cm enlargement. This does not cause a significant distortion to the block construction, but it is worth understanding these variations when the precise accuracy is required. This study considers that acquiring an additional full length measurement at the centre front can assist in a better length conversion.

Unclear indication of the bodice planes

There are a variety of methods used to mould a garment stand using a non-stretch fabric. For the practical requirement in the mass clothing market, the placement of the bust dart in the close fitting bodice block is often located at the side neck or centre of the shoulder. This location of the bust dart may be easier for further modification to a garment pattern, but it does not help in understanding the real body planes. In particular, when a non-stretch fabric is used to drape the garment stand for a close fitting bodice block, it is important to build a view of how the fabric would naturally bend along the curvatures of the garment stand in relation to the human body.

⁵⁶ This refers to an effective vertical measurement, e.g. the measurement is taken in consideration to the 'net bodice block' (see next footnote). For example, in particular the front waist length on the human bodice is located at the groove between both bust points. However, if applied to block construction, the measurement taken we should consider its relative height to the bust point. The front waist length on the human body is absolutely shortened than on the 'net bodice block'.

Unavailable 3D block validation

2D manual block cutting knowledge is based on long-term empirical experience, however, it always has to wait until the drafted block is assembled and tried on a live body before final approval can be made. A ground base for the practical garment type can then be established. The try-on process is mainly based on the assessment of the *garment fit* of the approval product (this will be further discussed in the section 2.5). The relationship between the human body form and the block appearance becomes the criterion to be assessed visually within an *estimating* condition which garment ease is usually invisible. It would be of great value if the analysis and assessment of this relationship could be obtained without the need for sewing 2D blocks together.

2.4.3.2 The prospective: 3D CAD applications

From this comparative study, it appears that individual block construction may be different, but there are still some similarities amongst the six blocks. An understanding of drafting variations and similarities gained from analysing cutting experts' work has provided some fundamental elements for this project. This research will examine whether current CAD technology has met the garment industry's demands (see Chapters Three and Five), and further to investigate the specific requirements of a computer-assisted design and cutting in a garment environment (see Chapter Six). The knowledge of block construction gained in this study showed that there are some fundamental elements in the construction of a close fitting bodice block. These fundamental elements, if applied to 3D CAD design and cutting, may be considered as:

An individual human body form

2D manual block cutting is working with a viable size chart. This size chart works with reference to a *human body form*. It should be also noticed that the size charts used are different from each other, which means each block refers to a preferred human body form type. This implies that some flexibility in the modification of a 3D CAD generated body

form to meet individual demand is required. The feasibility of modifying the shoulder slope and body posture should also be considered.

When modelling on a garment stand, it should be recognised that a *net bodice block*⁵⁷ is not the same as a 'skin' taken from the human body form. This is because, in particular working with a non-stretch fabric, a 'net bodice block' does not *mould* the human body form in wet-like calico, but very often needs to bridge the body's concave areas, e.g. the grooves between two bust points and two shoulder blades. In order to obtain a 3D CAD generated net bodice block, the 3D CAD generated body form will have to be modified.

The 'balance' requirement

With reference to the balance of the 2D or 3D block construction, the symmetric balance of the human body form should be considered. Although it is commonly known that a human body form may often be asymmetric; for mass garment production, it is necessary to ensure that there is a consistent horizontal and vertical relationship with the fabric grain, and that there is a symmetric relationship between the left and right bodice parts. Traditional 2D block cutting only drafts the front and back blocks, then makes the front or back block 'mirror' to obtain its counterpart. In generating a 3D CAD net bodice block, it will require a function, for example, the 'mirror' duplication⁵⁸.

Shaping the block: using the landmarks and structural lines

In order to model the close fitting bodice block on the garment stand, some identifications are required to be directly visualised. These identifications include marking the landmarks and taping the control measurements and the structural lines which are used to shape the contours of the garment stand.

⁵⁷ This is referring to a bodice block which is obtained from *moulding* a garment stand using non-stretching calico. *Ideally*, this block is ease exclusive, e.g. no ease exists at the side neck points, prominent bust and blades areas and the waist level. However, a small variation of the tightness is inevitable.

⁵⁸ A 'mirror' function in garment CAD can offer a counterpart to the existing 2D pattern or 3D garment stand through flipping along x or y axis.

As will be seen later (Chapter Six), while working in the 3D CAD generated block cutting, 'marking landmarks' and 'measuring' functions are necessarily required for achieving the tasks. The 'marking landmarks' function should also consider the feasibility of the automatic placing of points on an identified line where needed. Those points may not necessarily refer to the anthropometric landmarks. It is vital that a 'measuring' function considers not only the feasibility of taking straight and contour measurements, but also the areas which consist of hollow and contour, for example the bust girth.

The distribution of the ease

In 2D/3D manual block cutting, the fit of the block is affected mainly by ease distribution. The ease distribution on the 2D block is clarified and specified in section 2.5. Sensibly, it would be desirable to see how the ease is distributed within a 3D CAD environment. Under this demand, it would involve at least two basic elements: a 3D body form (or garment stand form) and a 3D 'net bodice block'⁵⁹. As individual need of ease distribution often varies, garment designers or pattern cutters may pad the mass-produced garment stand in order to meet their needs. Therefore, it would be desirable that these two elements (i.e. body form and net bodice block) could be obtained and modified easily.

Retaining identified circumference lines of the block

In 2D and 3D manual block cutting, retaining the circumferences of the block (i.e. block dimensions) is the key to achieving a successful block on a garment stand. Therefore, if applied to a CAD generated block in three dimensions, all the identified lines in relation to the block circumference on the 3D should be retained as they are in 2D. This requires a reliable conversion between 3D and 2D in the CAD environment, e.g. it is desirable that all the identified lines which are generated on the 3D CAD generated block are retained if they are transferred to a 2D environment for manufacture.

⁵⁹ A 'net bodice block' refers to a block which smoothes the concave areas of the bodice (e.g. between bust points and blades), simplifies the complex bodice curvatures, and is 'contact-fit' to the bodice.

2.5 The Term 'Fit'

2.5.1 Historical Use

The *fit* is one of the most fascinating factors in the fashion design sphere. In the fourteenth century, evidence from 'brass-rubbings' in churches showed that clothes had shifted from loose wrappings to 'cutting to reveal the shape of the figure', in particular, the smallness of the waist. Since then, garment 'cutting' has inherently been committed to an important role in clothing history, because people often give more appreciation for the slim elegance and the physical type of the body (Laver, J. 1969, pp. 28, 31-32).

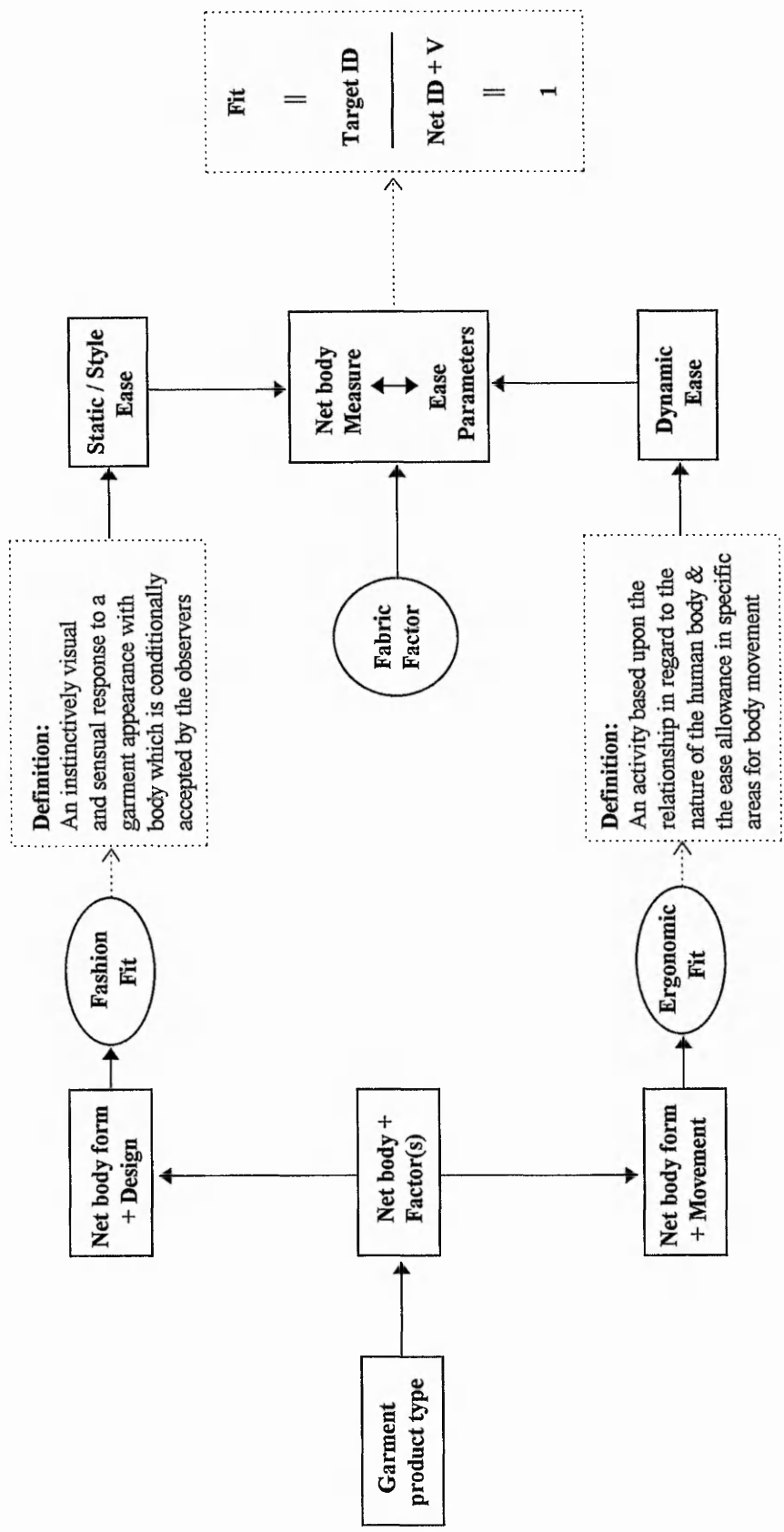
The term 'fit' is problematic because it is applied inconsistently, and is compounded by a general lack of agreement about the essential elements (Morgado, 1996). People interpret it through their individual appreciation of the garment appearance in relation to the body form at the current time and expect the others to have the same understanding.

J. C. Flugel, a Professor of Psychology, established the theory of the 'Shifting Erogenous Zone' (Laver, 1969, pp.36-7) to analyse how fashion operates. The theory stated that 'fashion' is based on emphasising the alternation of the seven themes in turn of the female body. This theory may indicate a chance of how the term *fit* was viewed from the relationship between the clothing and the body. These seven themes are : the Breasts (Neckline), Waist (Abdomen), Hips, Buttocks, Legs, Arms and the Length (Circumference) of the body itself⁶⁰.

The understanding or the use of the term *fit* in relation to different garments is often very varied. This is particularly true in the relationship which exists between the designer and the cutter, the managerial staff or market salesmen. Therefore, it is important to establish a mutual understanding and usage of the term garment fit. A statement regarding a model for the bodice garment fit at pre-production stage is shown in Figure 2.15.

⁶⁰ Professor Flugel's theory has influenced the structure of the model provided in Figure 2.15.

Figure 2.15 A statement regarding a model for the 'garment fit' at preproduction stage



Note: 'ID' and 'V' refer to 'Identity' and 'Variables'; the statements in the dotted boxes are supplementary to the structure of the model (see section 2.5.3.3, p.2-60).

2.5.2 The Term 'Fit' Applied to Current Bodice Block

Current use of the word *fit* in relation to a garment block is diverse in the clothing industry. A clarification of the fit is offered (see Figure 2.15) in order to establish a consistent and identical understanding for the fit in a coded model. Amongst current garment cutting literature, the use of the word *fit* to identify the nature of the garment appearance in relation to the block and body is often described in a number of ways, for example 'fitted, close fitting, leisure fitting or loose fitting'. Because of this discrepancy in interpretations, different ease distribution is required at each identified part of the bodice: first, with regard to product type, and second, with reference to the amount of ease used. This is discussed in the next section.

2.5.3 A Model for the 'Garment Fit'

For a specific *garment product type* (e.g. blouse or jacket), 'garment fit' is used mainly to evaluate the relationship between a garment and a live human body. Therefore, the evaluation is based on a *net body* and the *factors* which affect this relationship. The model regarding the 'garment fit' principally divides the relationship into two main strands; the 'net body form and design' and the 'net body form and body movement'. The first is subject to the 'fashion' factor whereas the second is subject to the 'ergonomic' factor. This is where there is often confusion and conflict in the concept of *fit*. In order to eliminate this confusion and conflict, the use of the word *fit* requires a precise statement.

2.5.3.1 A clarification to the meaning of the garment fit

Regardless of the production factor (imposed later), principally 'fashion' and 'ergonomic' are the two main strands in relation to the garment fit. Garment fit in relation to fashion (i.e. 'fashion fit') is an instinctively visual and sensual response to a garment appearance

on a body which is conditionally⁶¹ accepted by the observers⁶²; whereas in relation to ergonomics (i.e. 'ergonomic fit') it is an activity based upon the nature of the human body and the ease allowance in specific areas for body movement⁶³.

These two strands of the garment fit thereby lead to the two different types of ease, namely *static (or style) ease* and *dynamic ease*. This also later becomes a basic norm to assess the fit of the garment. The development of a model for the term 'fit' is hence subject to three main elements: the 'net body measure', the 'ease parameter' and the 'fabric'⁶⁴. It must be noted that the type of garment product has been primarily specified, thus it can be stated that the concept of *fit* and its relationship to net body measurements and the ease parameter can be clearly shown in the model offered in Figure 2.16.

2.5.3.2 A fit-coding method of stating the bodice garment fit

This model is coded with six main variables; the date, the net body measure, fabric, and the respective identified ease required for the principal, supplementary and additional (style dependent) measures.

The 'principal measure' consists of the bust, waist and hip girths, the 'supplementary measure' consists of the back length, across front, across back, armscye depth and front waist, and the 'additional measure' consists of the measurements which are subject to the fashion style. However, the five basic elements which are necessary in this measure are namely, the shoulder⁶⁵ length, the neck girth⁶⁶, the side waist, the total length and the hem width. The last two measurements are coded respectively in conjunction with the back length and hip (or waist) girth. This fit-coding method (see Figure 2.16) provides a view of how each individual ease is distributed around the bodice.

⁶¹ The conditional acceptance of the fashion fit is subject to the time, region, life style and individuality.

⁶² The observers at least include the designer, cutter, wearer and viewer.

⁶³ This refers to the 'comfort' and 'function' factors for live body movement.

⁶⁴ The 'fabric' factor is preserved in the scope of this study.

⁶⁵ This is principally referred to the front shoulder length.

⁶⁶ The neck girth would consist of the front neck and back neck.

Figure 2.16 A method of coding bodice garment fit using six variables

Company :	_____	Unit : cm (/or inch)
Principal:	Bust <u>net / ease</u>	Fabric Sample: Type Code:
	Waist <u>net / ease</u>	Date:
	Hip <u>net / ease</u>	Fabric Code:
Supplementary:	Back L. <u>net / ease</u>	Style Illustration:
	Across Front <u>net / ease</u>	
	Across Back <u>net / ease</u>	
	Armscye D. <u>net / ease</u>	
	Front Waist L. <u>net / ease</u>	
Additional:	Shoulder L. <u>net / ease</u>	
	Front Neck G. <u>net / ease</u>	
	Back Neck G. <u>net / ease</u>	
	Side Waist L. <u>net / ease</u>	
	Total L. <u>net Back L. +/- extra quantity</u>	
	Total Hem <u>net Waist/Hip +/- extra quantity</u>	
	Sleeve L. <u>net / ease</u>	
	Armscye G. <u>net / ease</u>	
	Specific ¹ <u>net / ease</u>	

Note: 1 'L', 'D', and 'G' are the abbreviations of length, depth, and girth.
 2 The '+/-' used in 'Total L.' and 'Total Hem' indicates 'longer' or 'less' than the net measure.

¹ This refers to the measure(s) which requires to be added for specific style.

2.5.3.3 The definition of the garment fit offered in this study

From this structure, we can identify exactly what the *fit* means when applied to a bodice garment product. The definition of *fit* offered in this study can be stated as:

$$Fit = \frac{\text{Target Identity}}{\text{Net Identity} + \text{Variable(s)}} = 1$$

The 'target identity' refers to the target measurement for the specific body area on the block, whereas the 'net identity' refers to the net measurement for an identified body measurement. The 'variable(s)' mainly refers to the ease parameter. This parameter is affected by niche market products which can be considered in several aspects, for example, fashion fit, ergonomic fit, the specific fabric, style or technical requirement. This definition was used, later in Chapter Four (see pp.4-16~17), for the creation of the sample garment form by applying cutting experts' basic close fitting blocks (see pp.2-39~49).

2.5.4 Contrasting Viewpoints

The structure in the Figure 2.16 not only attempts to specify the fit, but also expects to elicit how the individual garment cutting expert controls the fit. Master garment cutting technology can be established and retained within a company. Figure 2.17 principally shows this expert information.

It is interesting to identify clearly each net body measurement in association with an individual appreciation of the ease distribution. This apparently shows that a variation for each individual block construction is inevitable. Some measurements on the block may not appear to have significant differences, but they are composed of different net measurements and eases. This project is convinced that using mathematical calculation to dictate the block shape is not acceptable, in particular without knowing the net body form beneath the block form. In order to verify this belief, it is worth examining the practical problems regarding 'fit' which occur currently in the clothing industry.

Figure 2.17 A comparison of fit amongst the selected six close fitting bodice blocks

	Kunick (1987)	Bunka (1994)	Aldrich (1994)	Shoben (1980)	Bray (1994)	Stanley (1995)
	Unit: cm					
Height	164.4	164	160-170	163.5	160-165	164-169
Principle:						
bust	87 / 7.3	88 / (N/A)	88 / 7.9	86 / 7	88 / 6.8	86-90 (N/A)
waist	65 / 5	69 / (N/A)	68 / 6	65 / 7	68 / 5.3	N/A
Supplementary:						
Back L.	40 / 0	(39) ¹ / 0	40 / 0	40 / 0	39.5 / 0	40.5 / 0
Across Front	31.7 / 2.9	N/A	32.4 / 2.6	N/A	37 / 0	N/A
Across Back	34 / 1.2	N/A	34.4 / 1	32.4 / 1.2	35 / 0	35.5 / 0
Armscye D.	19.4 / 1.5	N/A	21 / 0	20.5 / 0	21 / 0	22.5² / 0
Additional:						
Shoulder L.	11.7 / 0.3	N/A	12.25 / 0	11.9 / 0.6	12.5 / 0	12.5 / 0
Neck ³ G.	36.8 / (N/A)	N/A	37 / (N/A)	36 / (N/A)	N/A	37.6 (N/A)
Side Waist L.	20.9 / -1.5	N/A	N/A	N/A	N/A	N/A
Total L.	N/A	N/A	N/A	N/A	N/A	N/A
Total Hem	N/A	N/A	N/A	N/A	N/A	N/A
Front Waist L.	35.1 / 1	N/A	N/A	N/A	N/A	N/A
Armscye G.	38 / (N/A)	38.5 / (N/A)	N/A	39.5(N/A)	42/(N/A)	42(N/A)

Note: 1 The 'N/A', 'L', 'D', and 'G' are the abbreviations for not applicable, length, depth, and girth.
 2 The 'total length' and 'total hem' girth will be referred to the 'nape to waist' and the 'waist measurement in finished pattern' in this comparison.

¹ This measure has been increased 1 cm in order to be consistent to the other blocks.

² The bolded figures refer to the 'finished pattern measurements'

³ The 'total' neck girth is used for this comparison because of the availability of the size charts from the selected six cutting experts.

2.6 Industrial Practice

After understanding the four main elements, i.e. *body*, *size*, *block* and *fit*, it was then important to know how current garment pattern cutting works currently. Two on-site visits were conducted in order to investigate the contemporary problems of garment pattern cutting. They were aimed at identifying the role of the 'basic close fitting bodice block' by clarifying the process between the concept design work and an 'approved garment product'⁷¹. Both investigations used the following process: first, the company types were clarified with regard to garment production; second, the determination of the body sizing was examined; third, the source of the blocks within the company was noted; fourth, the process between the design work and an approved garment was clarified; and finally, the use and limitations of 2D garment CAD systems were identified.

2.6.1 Company Types

The two companies visited, Martin Emprex International (Appendix 11) and Meritina (Appendix 12), work on a 'design through to manufacturing process'. This means that the company submits its original design work to the 'buyer' company, i.e. the major retailer. This submission consists of style design, colour palette, prints, fabric, pattern, trimming and price. If the style is selected, the manufacturer is then required to make up the selected garment product in accordance with the specific garment sizes and measurements provided by the buyer.

Under these circumstances, companies of this type are not in the position to give the final approval of their products. This is because the final garment product, in particular the agreement of the garment 'fit', is usually determined by the buyer company and that is usually time consuming and costly because many sample garments are required.

⁷¹ An 'approved' garment product refers to a completed garment sample which the style design, fabric, patterns, trimmings, 'fit' and costing elements have been agreed by the buyer and manufacturer and is ready to be sent for bulk production provided all the manufacturing requirements are satisfied.

2.6.2 Body Forms and Size Ranges

There was a difference between the companies in the underlying base of their work. This was in the garment stand (which represents for them the body form) and the size charts which they applied. The first company used general garment stands which were produced by the main garment stand supplier, 'Kennett & Lindsell'. These garment stands were produced in accordance with British Standards in women's size ranges. This could also vary for different body forms and shapes. The second company used the garment stands which were provided by their buyer company. These garment stands were specifically produced with regard to the buyer company's ideal body form and shape. This was often in accordance with the result of body surveys which were held by the major retailers.

It would be interesting to examine, over a period of time, if using the garment stand provided by the retailer resulted in more agreement at final fittings than if a basic commercial garment stand was used⁷². However, the second company must have judged the provision of a specific idealised body form to be of value.

2.6.3 Block Source

In an investigation of the agreement of the garment fit between 'buyer' and 'design and manufacture' companies, it is vital to look at the source of the basic blocks. Each company used close fitting 'basic blocks'⁷³ provided by the buyer company, such as the major retailer, Marks & Spencer. They were initially drafted by pattern technologists who were mainly from the buyer company's suppliers, e.g. Martin Emprex International (MEI) or Meritina. After being agreed by the garment technical manager in the buyer's company, these blocks were then circulated around the buyer company's suppliers.

These blocks, whilst being circulated around the manufacturers, were all given without instructions. Designer and cutter were expected to recognise some basic landmarks in

⁷² This study was a limited study and sees that this question would require more in depth research.

⁷³ This refers to Appendix 9.

relation to anthropometry and garment construction with reference to the size charts and measurements provided. When blocks did not provide a satisfactory base to create the design, designers would resort to working on the garment stands to produce a 3D manually modelled block.

2.6.4 Basic Processes of Approving Garment Design and Fit

2.6.4.1 Design brief

Designers and marketing staff were required to attend a design brief meeting ('orientation meeting' used by MEI; 'palette meeting' used by Meritina, Figures 2-18~19). This meeting was held by the buyer companies to provide seasonal fashion information which consisted of theme (story), colour, fabric, measurements & size charts, blocks, style design, fitting requirement, cost range and other relevant information.

2.6.4.2 Design submission

After considering all the requirements gathered from the design brief meeting, designers then started their design concept drawings. They searched for the desired colour, prints, fabric structure and finishing, and then they created their first 'trial sample'⁷⁴. This trial sample would first get internal approval and then be ready for the external submission. The submission at this stage would consist of all the requirements from the design brief meeting (this would all be contained in an envelope which was named 'log'⁷⁵); however, this trial sample was not necessarily to be made up with the 'submitted' fabric. The assessing elements at this meeting were based mainly on each buyer company's niche market demand, for example, the colour, the prints, the fabric, the satisfaction of the style design, the manufacturing process, and the cost.

⁷⁴ This trial sample was not required to use the 'final-selected' fabric.

⁷⁵ This is a term, used by both companies, which refers to a set of documents with regard to all the requirements for the selected garment product, e.g. measurements, size charts, blocks, fitting, making-up specification and quality requirements.

Figure 2.18 The relationship between the buyer and MEI

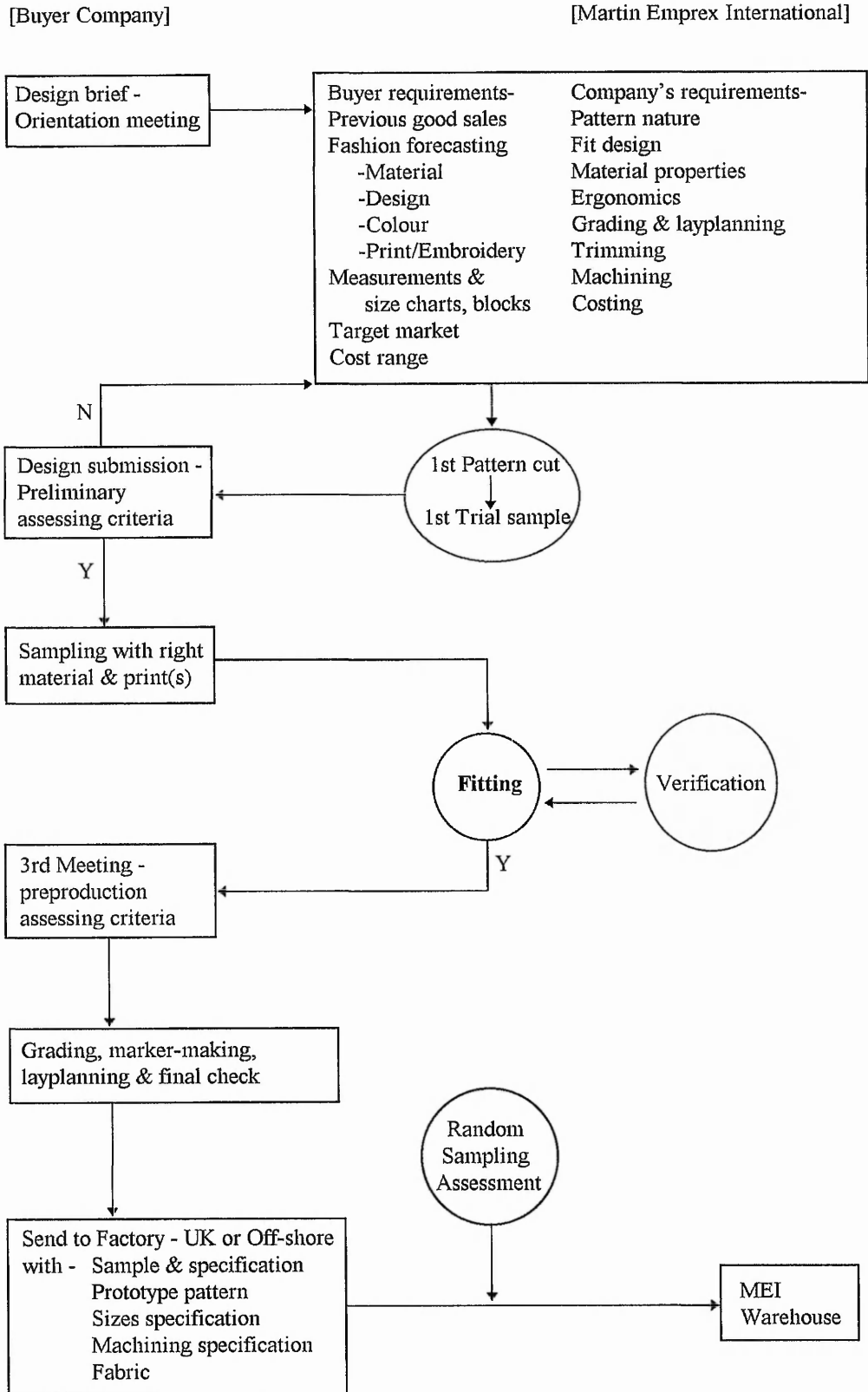
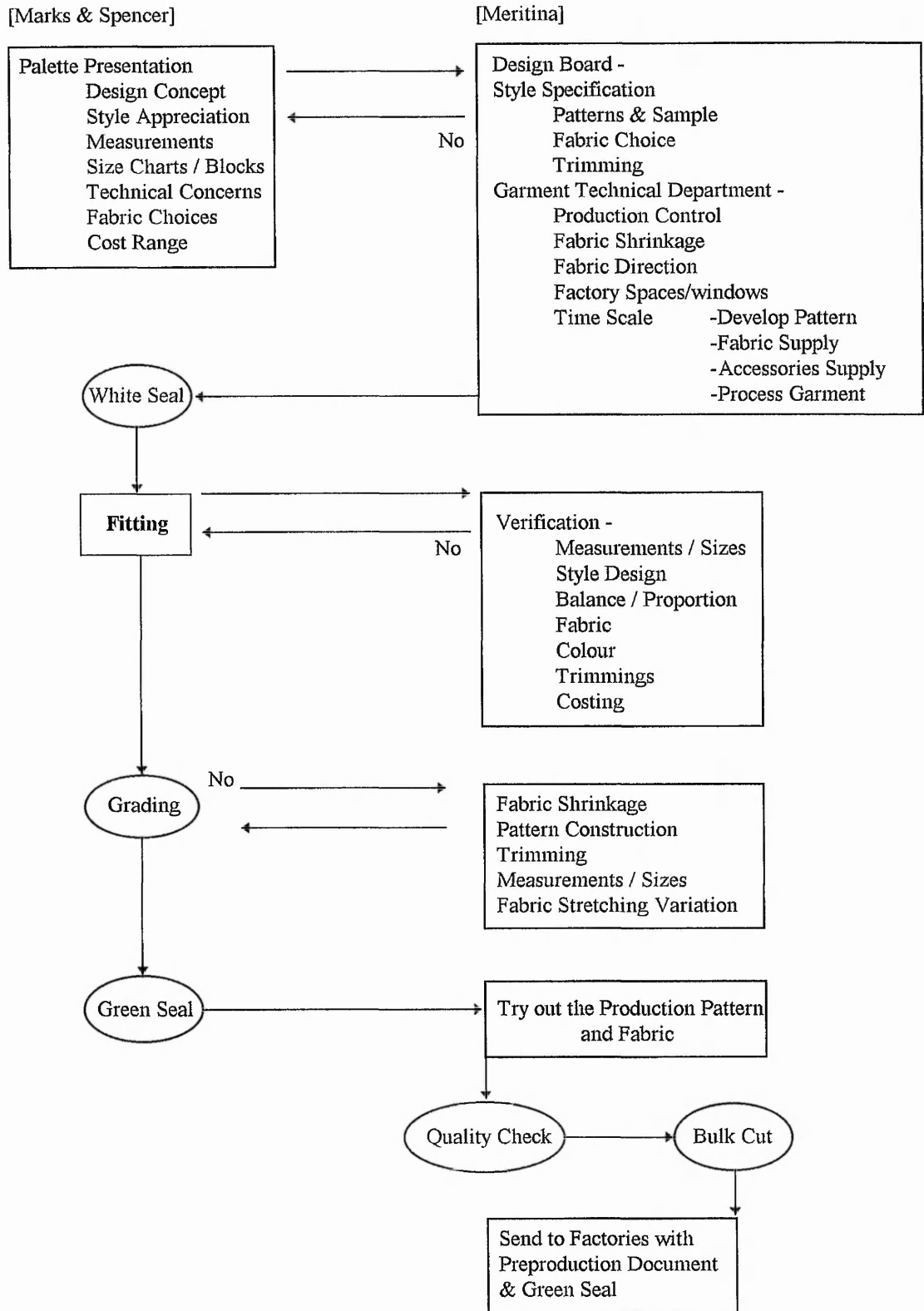


Figure 2.19 The relationship between Marks & Spencer and Meritina



2.6.4.3 Design and fit approval

Once the design drawings and trial samples were selected by the buyer company, the first 'garment sample'⁷⁶ was required to be made up in accordance with the buyer company's specific requirements regarding sizes, measurements, blocks, design alteration, manufacturing, fabric quality, costing and other relevant elements; however, it is acknowledged that final sizes and fit are not usually determined at this stage, as only a proportion of style ideas would be selected for production.

The criteria for the assessment at this meeting were based on the satisfaction of the style design in conjunction with the garment fit (see Figure 2.15), in particular the 'dynamic' requirement. This process was time consuming, for a satisfactory garment design was not necessarily a satisfactory garment fit in terms of fashion fit or ergonomic fit. The major problem was that it was rarely possible to find a human body whose body form, shape, posture, and proportion was identical to the garment stand supplied by the major retailers. Although they would emphasise that mass produced garments were meant to 'fit' the majority of people, the feasibility of producing a good quality of garment fit from the present irregular 'trial and error' process could be questioned because the fit of a garment to one human body would not adapt to another. This problematic process was repeated until the garment was fully approved by the buyer companies. There were other meetings before final approval, as samples graded into sizes had to be submitted.

2.6.4.4 Pattern validation prior to further plan for bulk production

Finally, after the selected garment was fully approved by the buyer company, the final preparation for the bulk production was started. There were several elements which should be taken into consideration for this preparation. These were: the fabric availability and quality, manufacturing and machining, grading and layplanning, cutting, making and trimming; and the final costing.

⁷⁶ This garment sample was required to be made up in the correct fabric and in 'final' product condition.

However, prior to any further plan for bulk production, pattern validation (i.e. checking patterns) was one of the most crucial requirements for the approval of a garment. In an example of checking a close fitting upper bodice garment, the main basic checking elements were: the final pattern edge measurements, the pattern shape in relation to the two adjacent pattern edges and angles (i.e. the seam lines), the dart angles/lengths in relation to the body landmark positions (e.g. the bust point), the grain direction of each pattern piece, and its shape development in relation to the original block.

2.6.5 2D Garment CADs

It was interesting to see that MEI and Meritina had 2D CAD systems, 'Cybrid - Layplan and Pattern Grading System' and 'Gerber - Pattern Design System' respectively, but none of them actually used the system to draft the block or modify the block to the desired pattern. The main reason which was given by both companies was that their heavy daily schedule did not allow an employee to become skilful on their systems, also they have become accustomed to the traditional 2D manual pattern modification.

However, both companies took great advantage of 'digitising manual patterns', 'grading digitised patterns', '2D design illustration', 'product data management, transferring and storing data', 'layplanning', and 'costing'. There was however still a lack of enthusiasm by designers and CAD suppliers to explore 'design and cut' and pull together the present divided operations of 'garment design and pattern cutting'.

2.6.6 Limitations

In considering Figures 2.18 and 2.19, from a new design to an approved garment product, on average, takes approximately 6-8 weeks in this life cycle. However, the most tedious process is generally caused when the 'fitting' is seen as unsatisfactory by the buyer company. This study was very interested to know why the buyer company was dissatisfied with garments initially 'agreed' by them.

In the first case, although several blocks were offered by the buyer company in different body measurements, size charts, ease requirements or even the buyer's garment stands, there was no means by which they could obtain a 'real' human body form from their garment stands. However, the 'fitting' process was carried on by trying them on several 'average' human models who represented the buyer company's niche market customer. This was particularly controversial, as the garment which fitted perfectly on one selected model was not necessarily perfect on the other one, even though the two models could be regarded as the average size.

In the second case, the buyer companies were expecting to see a realisation of the design sketch. However, in practice, this was not always the case. Because of the diverse understanding of 'fit', a general agreement of 'fit' is difficult to hold. In particular, whilst making alterations to the provided block to follow new fashion styles, the agreement of 'fit' is even more controversial.

This study acknowledged that there are differences between the privately owned companies, where there is often an historical evolution of block construction and fit standard, and large manufacturers and major retailers where block making and fitting techniques change constantly because the appreciation of fit is done by designers and pattern cutters who are often transient members of a department. This research argues that it could be a benefit for garment manufacturers and major retailers if all the informed knowledge in this Chapter could be established in the modern technologies available.

2.7 Summary

It is apparent that many discrepancies and anomalies arise in the whole area of body, sizing, block construction, and fit.

Body sizing implies not only the importance of the control measurements of a garment, but also demands the establishment of a consistent size chart for an adjustable net body form which means that the body form, shape, posture, and proportion can be modified to meet individual need. This study is convinced that the establishment of a computer generated net body form in accordance with niche demand may be of great advantage for the mass clothing industry to provide consistency. This research identified that the specification and modification of the net body form would be one of the most fundamental requirements to enable a garment designer or pattern cutter to carry out his/her ideas.

Pattern experts' individual concepts of block cutting and the variations they offer to designers are valuable. The problems occur when there is no knowledge of the idealised selected body form which underlies their interpretations. This is where the problems arise. Currently, buyers use the real human body (i.e. the in-house model) to examine 'dynamic fit' and use the specifically produced garment stand to examine 'static fit' (see section 2.5.3.1). Above all, individual appreciation of the garment fit is a crucial key to investigate garment design and pattern cutting. However, having noticed that it is rarely possible to find a human body whose body form, shape, posture, and proportion could be identical to a mass produced garment stand, it is highly questionable that major retailers still use both 'criteria' to establish *standard* garment fit. Nevertheless, it is important to clarify each individual with each variation, and this may require modern technologies. Appropriate technologies may not be yet available, but it is clear that whatever modern technologies are developed, the feasibility of carrying out each individual requirement for each individual garment manufacturer or major retailer is seen as the priority task.

In considering this requirement, it was decided that the three main elements, i.e. the net body measure, the ease parameter, and the fabric (see section 2.5.3.1), which were seen to affect the use of the term garment fit would be the most important elements to control.

However, the first two elements could be considered together in the realisation of the 'garment form' which, in the real world, would be determined by the constructed 2D pattern shapes. This garment form would not include the factors of fabric construction and grain direction. Therefore, it was necessary to investigate the 3D and 2D manual methods of block construction before considering how a garment form would be used in the real and virtual worlds.

This study has also claimed that the way garment pattern cutting experts are working conflicts with the way current modern garment technologies operate. This leads the project into an investigation of the limitations and potential of modern 2D/3D technologies available for use in the garment industry. Other relevant design industries (e.g. the shoes, furniture, and automotive) and academic research will also be investigated, so that full advantage can be taken from existing knowledge.

3 INVESTIGATING 2D/3D GARMENT CAD SYSTEMS

3.1 Introduction

In the second half of the twentieth century, a new computer technology was invented. This new invention has encouraged a series of advancements in production in the garment industry. In due course, starting in the 1970s, this technology was applied to 2D patterns. The initial impetus was to generate pattern control data for automatic fabric cutting machines. This required pattern shapes and arrangements in digital electronic format. The obvious progression was to automate pattern¹ grading and assist pattern lay planning. This may be regarded as the first stage in the application of computer technology which influenced the clothing industry (Knox, 1994; Taylor, 1990; Jo, 1989; Turner, 1986; Efrat, 1982).

With the success of computer assistance in 'grading and layplanning'², computer technologists shifted their attention to the design of garments. Amongst these computer driven systems, there were two main areas (Figure 3.1): the 'concept design system' and the 'engineering design system'. The concept design referred to sketching or painting (raster³), e.g. garment or textiles design (i.e. colour, prints or texture), whereas the engineering design referred to drafting constructive lines using mathematical calculation (vector⁴), e.g. drafting garment block or pattern in accordance with the sizes, the measurements and the fit (as stated in Chapter two). It is important to note that drawing and drafting applications have significantly different functions. This study adopts the classification of concept design and engineering design, but for general use in the clothing industry, 'pattern⁵ design system' ('PDS') is used instead of 'engineering design system'.

¹ Private talk with Knox, dated 1 September 1997. The last two factors were also stated by Turner (1986, p.39) and Taylor (1990, p.23).

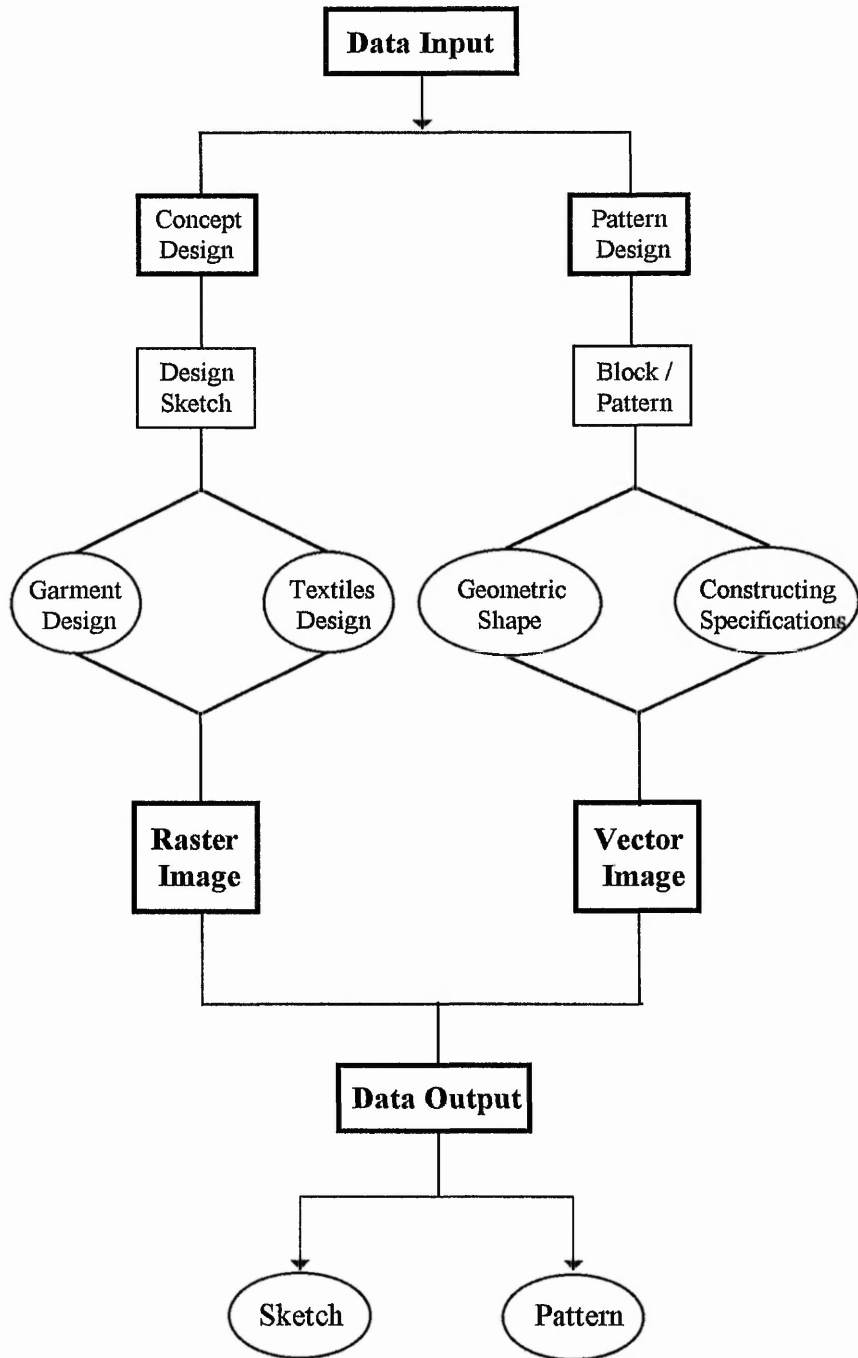
² These two elements will be classified into the 'manufacturing' factors in this study.

³ 'Raster' images are created using square shaped dots (pixels) which can be filled with block colour.

⁴ 'Vector' images are produced by line segments. The outline shapes, which are made up of a number of control points, can be easily manipulated to alter the image. This technology is mathematics based.

⁵ The use of 'pattern' in this context is widely understood as 'block and pattern'.

Figure 3.1 The distinction between the *Concept Design* and *Pattern Design* in the 2D apparel CAD systems



In turn, CAD systems also can be classified into 2D and 3D. 2D concept design systems have made a great contribution in terms of concept representation, e.g. the effect of print repeats can easily be scaled proportionally, or be re-located without the need for re-drawing. The quality of 2D-PDS has also shown a success in digitising block or pattern, grading, and lay planning. This can be proved by the fact that 'many of the large and medium garment manufacturers have implemented this technology'⁶. However, 2D-PDS has not yet provided viable assistance in bridging the gap between design concept and pattern making technique.

At present, the 3D apparel CAD is in development to bridge this gap. This is intended to visualise and approve a garment product without making-up a trial or sample garment, i.e. once a garment style design is selected, the electronically flattened 2D patterns could be ready for production use. There may be 3D software available in other manufacturing industries, e.g. AutoCAD, UniGraphics, ProEngineer, Alias, and Shoemaster, or in the clothing industry, e.g. Concept Design Inc. (CDI) and Asahi Chemical Industry Co., but there is little evidence of this being successfully utilised by garment companies⁷. The reasons are not only because 3D software is generally complex and costly, but also because the functionality of this modern technology is deficient, as this thesis will confirm.

Clearly, it would be of great value if the functionality of this developing technology, linking new 3D garment form to proven 2D pattern, could be assessed and verified. This would require traditional manual pattern making methods because electronic pattern stability has not yet been confirmed by the garment pattern making expertise on which this study will be focused. These skilful techniques of making garment patterns are often underestimated. As Nancy Staples stated in Kalman (1997):

...such developments in technology make it easy to overlook one of your greatest assets - your pattern maker - whom she called the "heartbeat" of a manufacturing organization....

As for the future, Staples said, "It is only the proficient pattern maker who will easily flatten the cyberpattern to 2-D to turn it into a garment, someone has to build that pattern."

⁶ Private conversation with Knox who has expertise in textile and garment CAD technologies (see references).

⁷ From the documentation and exhibitions we have researched, the 3D CAD software is merely used for the bra product section by garment research groups in Europe, such as the 'Textilforschungsinstitut' (Textile Research Institute) in Germany (The 'IMB' exhibition in Cologne, 1997).

This confirms that it would be of great value for the future of the garment industry if manual pattern cutting expertise could be adapted to modern 3D CAD technology and enable patterns to be made effectively and efficiently at the pre-production stage.

Current related academic research focuses mainly on applying mathematics to produce patterns (Akiyama et al., 1994; Hinds and McCartney, 1990/2; Efrat, 1982). Clearly, it is pattern making expertise which is used to approve the pattern. This study is therefore aimed at exploring the limits and taking advantage of the software available using manual pattern making expertise. An investigation of some of the 3D software available has been conducted (see section 3.4.1), and the CDI 3D software has been adopted for this study because it provides the program of flattening a pattern from 3D to 2D and is the most highly developed system commercially available.

Current research (McCartney, 1998⁸, Govindaraj and Ruff in Nannery, 1996; Stylios et al., 1995) is concerned mainly with the 3D draping sector, e.g. 3D fabric pattern simulation. It is worth noting that 3D apparel CAD systems would be more valuable for the garment industry providing that the 3D concept design can be realised and approved by 2D pattern making. This study therefore concentrates on investigating the 3D-PDS sector, the fabric draping factor is beyond the scope of the discussion.

This chapter discusses the themes as follows: the garment CAD evolution; the system structure in relation to current 2D-PDS and 3D apparel CAD system; systems link, which is provided for validating the later assessment of the conversion between 2D and 3D; and software available in the relevant design industries and investigations of the related academic research units.

⁸ Direct contact with Hinds and McCartney, dated 8 May, 1998. Researcher Gong is dedicated in 2D to 3D draping and researcher Loo is dedicated to improving the accuracy of 3D to 2D flattening (for details, see section 3.5, p.3-74).

3.1.1 The Garment CAD Evolution

The first computer-driven device was developed to cut cloth in the early 70s. (Knox, 1997⁹; Taylor, 1990). In due course, with the Autographics software company's help, Hughes Aircraft Company based in Carlsbad, California, marketed a system to manage two of the important pre-production tasks in the clothing industry, grading and layplanning. This system was known as 'AM1' computer aided 'engineering design'¹⁰ system of which the first system was installed in Louis Goldsmith, a menswear company based in Philadelphia, in 1972 (Knox, 1975). Camsco, based in Dallas, was the other competitive company who produced similar grading and lay planning software. This was called the 'Markamatic layplanning system' (Knox, 1975).

In the late 70s, the American Gerber Garment Technology (GGT) bought the AM1 system from Hughes. Competitors from other countries were also starting to launch into this development, such as Lectra from France, Investronica from Spain, and Asahi from Japan (Taylor, 1990, p.23; Sato, 1990, pp.96-100; Knox, 1994, p.21).

As computers developed more powerful hardware in the early 80s, this new change not only reduced the cost of the computer driven equipment, but allowed the systems to run more effectively (Knox, 1997).

During this time, Lectra commercially launched a brand new system with its own laser cutting device and computer-driven technology, and GGT upgraded the original AM1 to 'AM5' system. Camsco gradually lost the market and was eventually taken over by GGT. More systems were then concurrently developed by the people who worked for Camsco but had left after the take-over by GGT. They were, for example, Microdynamics in the US and Assyst from the former W. Germany. There were other competitors such as Polygon and CDI from the US, Bullmerwerk and Cuttex from former W. Germany, Ormus and Cybrid from the UK. Shima Seiki and Yuka from Japan, also launched software in this field (Taylor, 1990, pp.24; Tait, 1995, p.19; Russell, 1996/7, p.14).

⁹ This historical section regarding garment CAD evolution was mainly based on a private conversation with Knox, dated 11 Sept. 1997.

¹⁰ Based on mathematical line drawing and calculation.

The personal computer replaced the new version of the mini computer in the late 80s, when it became cheaper and more capable of running the software. This meant that more clothing companies could take advantage of this new technology. As more professional users were involved in this technology, the more specific professional market demands increased relatively. These demands led suppliers to develop a new computer aided design software which would consist of concept design sketching and pattern design systems (Knox, 1997).

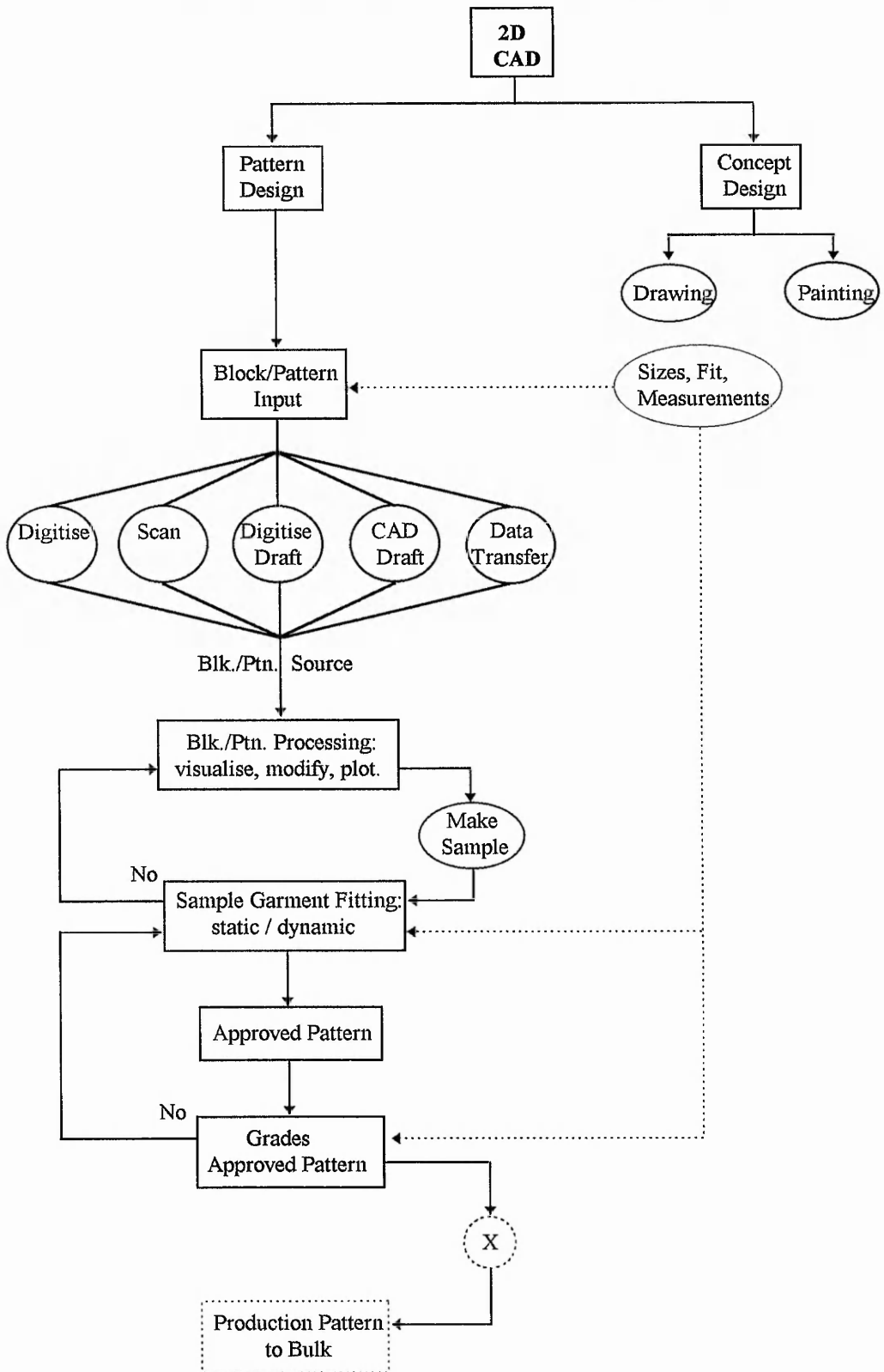
Computer Design, Inc. (CDI) may have been the first software company which brought the '3D grid' and the 'contour mapping' techniques into CAD development ('IMB', 1997). This enhancement implies the possibility of communication between the pattern design and concept design. However, there is no evidence to show success linking a 3D concept design with 2D patterns (engineering) from the commercial CAD systems available. Yet the sample garment fitting process was very time-consuming (see section 2.6.6). This shows a demand for 3D apparel CAD linked with 3D-CDS and 3D-PDS. Up to the present, many companies claim to offer 3D CAD capability, e.g. the PAD, Assyst, and ModaCAD, but true 3D major players which have launched their 3D apparel CAD software commercially are CDI from America (taken over by Lectra in spring, 1997) and 'Asahi Chemical Industry Co., Ltd' (Asahi) from Japan (see section 3.4.2).

3.1.2 The System Structure

3.1.2.1 The current 2D-PDS structure

The system structure which current 2D-PDS use basically contains data input, pattern design, and data output. The data input refers to inputting blocks or patterns for the 2D-PDS. This consists of five methods, i.e. digitising, scanning, CAD drafting, digitiser drafting, and data transfer (Figure 3.2). The data regarding the geometric shape of the 2D block or pattern construction is linked with body measurements, sizes, and fit requirements. The pattern design principally refers to the creation of new garment patterns or the modification of the input garment blocks or patterns for new style design.

Figure 3.2 System structure in relation to current 2D pattern design



Note: The variables of 'sizes, measurements, fit' and the textiles are exclusive to discuss in this diagram; the 'Blk' is short for block and the 'Ptn' for pattern; Also, the 'X' in the dotted circle is referred to the preproduction of the 'marker making, layplanning, costing and machining...etc.'

The majority of garment patterns are made using the latter method, e.g. Martin Emprex International, Meritina (see section 2.6), and S.R. Gent International¹¹. Finally, the data output refers to the completed 2D block/pattern. The output data can then be developed for the final production pattern (e.g. grades approved pattern) or transferred for further applications (e.g. lay planning, or costing). This often requires a link-up with a device, such as a printer or plotter, to provide the pattern shape to scale or full size.

Despite the fact that there may be commercial software available to check automatically the drafted block/pattern, e.g. the 'Check Point' system (Wilson, 1995), the 'computer-aided pattern technology'¹², there is scant evidence of its use because there is no need to check the block or pattern if it is not proved to be a designer's concept design. This shows a need to develop a 3D-PDS to bridge this gap.

3.1.2.2 The current 3D-PDS structure

For use of garments, this consists of the garment stand data input, 3D modelling and 3D image (simulation) software, pattern flattening, and transfer to 2D pattern processing (Figure 3.3). Main elements are explained as follows. First, 3D scanning or 3D digitising is used to obtain the garment stand because a garment stand form is too complex to be constructed using a synthetic 3D (x, y, z) co-ordinated system. Second, 3D modelling is used to develop the prototype garment using the input garment stand, and 3D image simulation (e.g. draping) is used to view the CAD generated prototype garment. Third, in order to obtain a 2D pattern shape, the flattening (i.e. 3D to 2D) function is attempted. Finally, the pattern data is then transferred to 2D-PDS for bulk garment production.

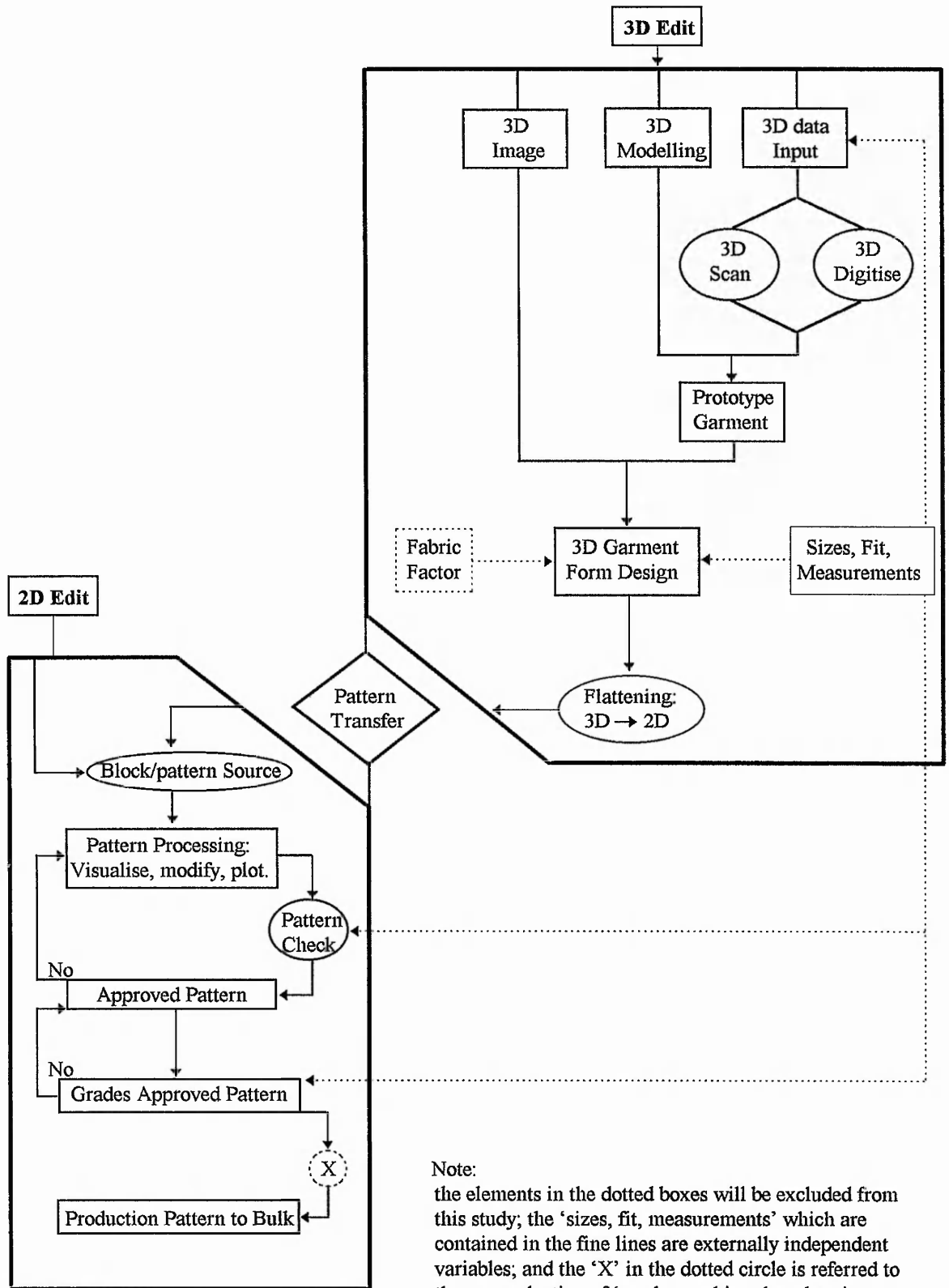
At present, despite the fact that the 2D-PDS link has been proved¹³ a success in production, it is noteworthy that there is still a lack of evidence to show the viability of the functions, such as flattening or draping, in the 3D-PDS.

¹¹ A direct contact with Mr. London, technical manager at the S. R. Gent International (1996).

¹² Leighton, the 'computer-aided pattern technology' software developer, demonstrated in the Nottingham Trent University, dated 22 Jun. 1998.

¹³ For example, Callow Maddox, a car seating supplier, based in Coventry (UK).

Figure 3.3 System structure in relation to current 3D apparel CAD



Note: the elements in the dotted boxes will be excluded from this study; the 'sizes, fit, measurements' which are contained in the fine lines are externally independent variables; and the 'X' in the dotted circle is referred to the preproduction of 'marker making, lay planning, costing, and machining...etc.'. Finally, the two main diagrams in bold contain the 2D/3D program structures.

It is important to note that the success of a 2D-PDS is primarily to manipulate a master basic block which garment pattern making expertise often takes for granted, whereas there is still a lack of evidence to show that this *master* block can be obtained by the current 3D-PDS.

To prove this claim, the fundamental requirements are: first, to establish a 3D CAD generated garment stand using 3D digitising techniques, this needs investigations of 2D/3D digitising technologies available (see section 3.2); second, to focus only on a pre-defined stabilised garment form with a foundation pattern, this needs an understanding of the available 2D/3D pattern design systems available, their limitations and potential for use in the garment industry (see sections 3.3-4); third, to investigate academic research in order to take advantage of existing relevant knowledge (see section 3.5); finally, to reach a conclusion about the deficiencies identified in the previous sections (see section 3.6).

3.2 Data Input

The input data can be divided into two main sections, 2D flat in (x, y) and 3D in (x, y, z) co-ordinates. The 2D data refer to the area and the outline¹⁴ of the block or pattern which enable the computer-driven device to identify the 2D block or pattern shape precisely, and to transmit the 'internal information'¹⁵ of the block or pattern effectively. The 3D data enable the computer to recognise any 3D form which is input or generated in three dimensions. This allows a 3D solid form, e.g. a garment stand, to be specified using the software.

The 2D pattern data can be created through five input methods: digitisation, scanning, CAD drafting, digitiser drafting, and data transfer. The 3D garment stand form data input can be created through 3D contact or non-contact digitising techniques. This is discussed along with the inputting device.

3.2.1 Input 2D Data: the block or pattern

The 2D data input refers to the transmission of an existing block or pattern into 2D-PDS through a 2D digitiser, scanner, or the PDS software itself. The input block or pattern can then become usable within the PDS. Different PDS systems may use different formats to generate a 2D pattern. Some specific examples are quoted from Gerber AccuMark because this study, later, will link the GGT AccuMark with the CDI-3D for experimental use. There are two different types of data used by GGT AccuMark to identify and generate block or pattern, raw data and processed data. Raw data contains a record of each identity of the block or pattern, which cannot be applied to other production use. In turn, the processed data has viable applications where the real data for the block or pattern is held. All the information about the geometry of the block or pattern shape can then be applied further to other production usage, for example, grading or lay planning¹⁶.

¹⁴ This can be called 'external information', as opposed to 'internal information', of a pattern shape.

¹⁵ The 'internal information' of the pattern refers to the grain line, notches, and drill points.

¹⁶ Mr. P. Rhodes from GGT explained the 'piece' and 'raw' data file format used by the AccuMark in a training course at the Nottingham Trent University, dated 7 July 1997.

There are three important factors for inputting block or pattern data. First, each pattern of the same garment should be consistent in grain¹⁷ whilst being input (this helps further grading application). Second, the selection of the point numbers of a curve depends on the degree of the curvature. With more points selected, the curve appears less smooth but closer to the real curve shape. Therefore, to obtain the desired curved shape, the number of points should be carefully determined. Finally, the accuracy of the output pattern and other internal information, e.g. notches and grades need to be assessed using the original manual pattern.

2D digitising

2D digitising is the process of inputting sets of co-ordinates (x, y) to identify the outline points of a pattern, the grading points, and other related information for that pattern (GGT, 1996). The most common method of inputting 2D block or pattern is using a 2D digitiser (Appendix 13). 'The digitiser..., under its surface is a very fine electrified matrix in a longitude and latitude configuration of x and y co-ordinates' (Taylor, 1990, p.92). Taylor explained this process as relying on :

....physical energy to depress the keys, each of which has its own code which will energize a pattern of light dots on a cathode ray tube (VDU, video display unit) corresponding to the letter or number. (Taylor, 1990, p.39)

In practice, there are some principles which can be applied generally. First, the geometric information about a block or pattern construction is needed. This consists of the grain line, the grading points, the line category (i.e. straight or curve line), the notch points, the internal points or lines, mirror or close the pattern piece. These are identified by an alpha/numeric (letters and numbers) puck with a cursor linked to a digitising table and a menu while entering the block or pattern. Second, the descriptive data information regarding the digitised block or pattern for production is also required. This contains, for example, the style name, the piece name, the grade rule table, the base size and size

¹⁷ The grain usually goes in parallel with the lateral direction of the digitising table.

ranges, and/or the quantity of the block or pattern piece to be cut. Finally, a larger piece of pattern, with some rules, can also be input by dividing it into smaller pieces.

The 2D digitising method can register a pattern shape within +/- 0.01 cm accuracy¹⁸, whereas usually +/- 0.025 cm accuracy is regarded as normal for digitisers used in clothing production. In practice, 0.1 cm accuracy is generally acceptable for clothing patterns (Knox, 1997). However, human error which may occur while matching the cursor to the selected points, limits the operation.

2D scanning

Scanning is another method of inputting block or pattern data. The device used for this is called a '2D scanner' (Appendix 14) which works like a photocopier. A scanning lamp with photo-detection capability is placed under the scanning table and it 'photocopies' the outline of the block or pattern shape. A scanner can also be linked to the 2D-PDS software, so that a scanned block or pattern can be visualised or validated.

The 2D scanning method may be easier, quicker, and, in theory, more consistent than the 2D digitising method in terms of accessing block or pattern data because it removes human error occurred in matching consistently the puck's cursor to the pattern outline. However, the 2D scanning method also has some constraints. They are, for example, the consistency of the 'photocopy' technique may be questioned, in particular, in the outer area of the photocopy screen. Also, there is a lack of internal information for a block or pattern, e.g. the internal points for buttonholes, notches or grade rules. More importantly, it 'copies' the human errors in constructing a block or pattern. Therefore, the 2D scanning method to input block or pattern data has not been used as widely as the 2D digitiser in the clothing industry.

¹⁸ This is featured in the Lectra's digitiser; P. Rhodes, senior technologist in Gerber (UK), believes that the accuracy of digitising mainly depends on the digitising operator's skill (private talk, Apr. 1998).

CAD drafting

The computerised block or pattern draft is another method for obtaining the block or pattern source. Unlike the previous two data input methods which require patterns produced elsewhere or by other means, this technique uses CAD software, itself. This technique is discussed with respect to the CAD draft and the digitiser draft.

The CAD drafting draws the block or pattern, using vector calculations which have been programmed into the pattern design system (see section 3.3.1). Fundamentally, the CAD drafting method requires size, body measurements, eases, and pattern specifications, such as seam allowances and notches. With a computational power, this method provides greater accuracy for all the horizontal and vertical lines, dart angles, and curve shapes than a manual drafting. Once the pattern is drafted, the data which relates to the geometric shape of the pattern is ready for use in any production application.

However, problems occur where the block is drawn on the computer screen within a miniature scale which makes the accuracy of the full size pattern shape difficult to be identified. Importantly, this method may be useful for some technical pattern cutters, but it is still limited in assisting a pattern cutter to interpret a designer's concept. Yet, it is often time consuming to master all these tools. Hence, another technique, such as on-line drafting (e.g. Gerber's Silhouette), has been developed to help pattern cutters work in a more familiar way, i.e. using a pen and paper, to draft patterns.

Digitiser drafting

The development of digitiser drafting solves the difficulties which occur with the CAD drafting. This method uses an electronic pen (or stylus) to allow freehand construction of a block or pattern or to duplicate a full-size block or pattern by copying the outline of the existing pattern. The Gerber company launched this technology, known as 'Silhouette', in 1991. Later, other competitors, such as Lectra, Investronica, and Assyst also developed and launched this technology in succession.

The basic components for the digitising draft consist of a digitising table, which is designed with an option of switching the PDS to the digitise draft program, monitor, keyboard, and digitising pen, or stylus (corded or cordless).

The main difference between general 2D digitising and the digitiser drafting in the GGT 'Silhouette' is that the first registers a pattern through the selected points of a pattern, using the digitising puck, while the other has three methods to register a block or pattern using the digitising pen (or stylus). These are drawing around an existing pattern, free hand drawing on the paper which is fixed to the digitising table, and selecting the points in relation to the geometric shape of the existing block or pattern. The digitiser drafting may have led 2D garment CAD to be more successful. However, it still has handicaps for designers who may not have the same skill as a pattern cutter.

Data transfer

This method refers to the pattern data which is obtained from a different file format. Initially, the demand for data transfer appears, when the raw digitised data is required to register as a pattern file in the same system, then, when the pattern file from one CAD system needs to communicate to the other CAD systems, and finally, when the piece file from the CAD system needs to be transferred to CAM systems for production. Common standard data transferring of a block or pattern is discussed in section 3.2.2.2.

3.2.2 2D Pattern Data Validity

In order to obtain an approved pattern, the pattern has to be validated. In this context, it can be split into two topics, pattern check and common standard pattern data transfer. The first is to check 2D patterns after being flattened, and the second is to validate pattern data which have been transferred from one system to the other.

3.2.2.1 The pattern check

There is also some software (e.g. supplied by GGT, Lectra, and Assyst) which offers checking functions, such as measure 'pattern walking' to help check seams for adjacent patterns (see section 3.1.2.1). In practice, it is to help check the geometric pattern shape rather than to examine the pattern cutting knowledge in the constructed pattern.

Often the process of 'pattern check' is still undertaken manually. The checking elements depend on the category of garment, e.g. shirt, skirt, or jacket. For example, the checking elements for a close fitting bodice block or pattern elements could be:

- (1) pattern periphery (i.e. measurements)
- (2) ease, (matching) notches, and seam
- (3) dart width/length
- (4) dart angle and ending point
- (5) matching adjacent patterns length/angle
- (6) one/two-way fabric and grain
- (7) numbers of pattern piece and pattern direction
- (8) 'ease-in' (e.g. the armscye length on the sleeve is usually longer than on the bodice because of the construction of the sleeve crown head. (The fabric is the key factor which affects the ease-in tolerance).

3.2.2.2 Common standard pattern data transfer

The standards of (vector) pattern data transfer mainly consist of: transferring 2D pattern data from one system to the other (e.g. from CDI-3D to AccuMark) and transferring 2D pattern data and associated data to a marker making system or cutter driver for production.

The most commonly used engineering (i.e. pattern) drawing data standards are: the Autodesk Inc.'s 'DXF' (Drawing Interchange File), and the 'IGES' (Initial Graphics Exchange Specification). The 'AAMA' (American Apparel Manufacturers Association) adapted Autodesk Inc.'s DXF format and developed a specific file format for garment

pattern. The establishment of standard pattern data provides the clothing industry with another opportunity to share the pattern source and the relevant information nationally (departments or domestic) or internationally (Allcock, 1997, p.38; DeWitt, 1994, p.46).

The basic structure for this pattern interchange file format is based upon Autodesk, Inc.'s DXF File Format which is widely used to transfer drawings and information between CAD/CAM systems in other industries. (AAMA-292, p.i)

A DXF file is a specially formatted ASCII text file. It consists of an optional header as well as tables, blocks and entities sections. The tables section allows for user-defined functional layering of a CAD drawing. (AAMA-292, p.1)

It is worth noting that specific standards for garment pattern data often contain several drawing elements which are not generally used by other design industries, for example 'grain line', 'notches', or grading rules (Knox, 1995, p.20).

With standard pattern data transfer, the CDI-3D electronically flattened patterns can be transferred to AccuMark and plotted in scaled, nested, or full size via a link-up with another 2D computer driven device, i.e. plotter. Also, with a minor modification to the AccuMark pattern file, which is converted as an AAMA format, the 2D pattern file can be imported into the CDI-3D system by means of the 'Import DXF' program under a directory of the Silicon Graphics. This study focuses mainly on examining the '3D to 2D' path by means of controlling identical experiments in the real world. The '2D to 3D' path is excluded in discussion.

3.2.3 Input 3D Data: the Human Body or Garment Stand

In the clothing sphere, the input 3D data usually refers to an actual human body or a garment stand. Garment stands, which are produced in a certain ranges of sizes, are essential in bulk garment production. This is because it would be extremely difficult to find a person whose body measurements are consistent with the size charts.

There are several methods used to create a 3D CAD generated garment stand. These are: 3D CAD drafting, 3D contact digitising, and 3D non-contact digitising (also known as 3D scanning). 3D CAD drafting is rarely used because the curvature of a human body or garment stand is usually too complicated to be constructed directly.

The principles which apply to 3D contact and non-contact digitising are similar. Both methods provide groups of set points to identify the 3D form. The work relating to both 3D digitising techniques have been done by a few suppliers. Examples of systems are Cyberware body scanner, the FaroArm, the MicroScribe-3D (Figure 3.4), the FlashPoint 5000 - 3D digitiser¹⁹, the Loughborough Anthropometric Shadow Scanner (LASS), the Topometric 3D-Sensor, the [TC]2's non-contact body measurement system, the Viro-2400 whole body scanner, and the Hamamatsu's Body Line Scanner (i.e. BL Scanner).

There are other methods of establishing a 3D CAD generated human body or garment stand, such as the 'Ultrasonic' and 'Magnetic' systems²⁰, but their accuracy for collecting data is subject to the conditions of the user environment which can be restrictive. The Swiss Federal Institute of Technology's modelling of the human body²¹ may be another potential application in the future (see the end of this section, p.3-42). At present, 3D contact and non-contact digitising are the most popular methods of collecting human body or garment stand data.

3.2.3.1 3D digitising

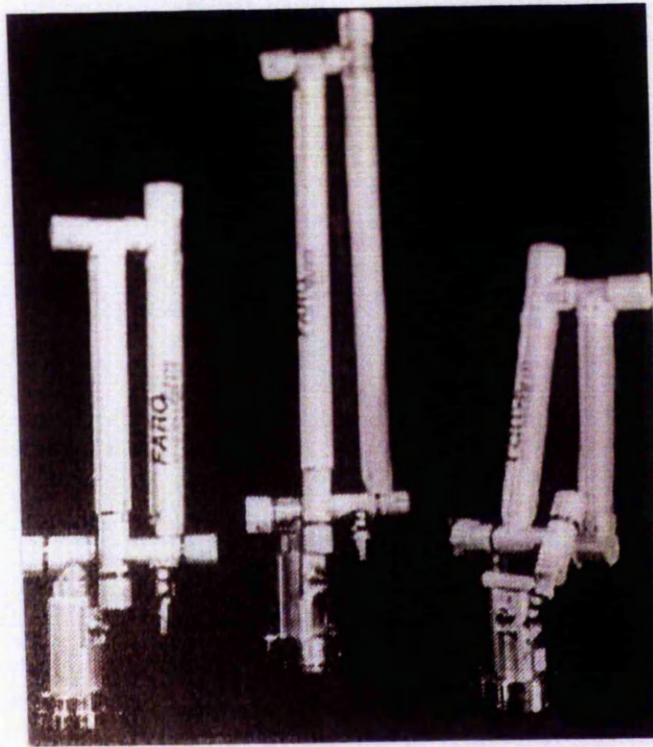
The basic components of a 3D digitiser differ from one to another, but they may principally consist of: a digitising device, a detecting sensor (e.g. a *sensor pen*, to probe the selected points), a dynamic device to reach measured areas, and an individual interface software.

¹⁹ Featured in the Image Guided Technologies Inc.'s web home address at 'www.ImageGuided.com'.

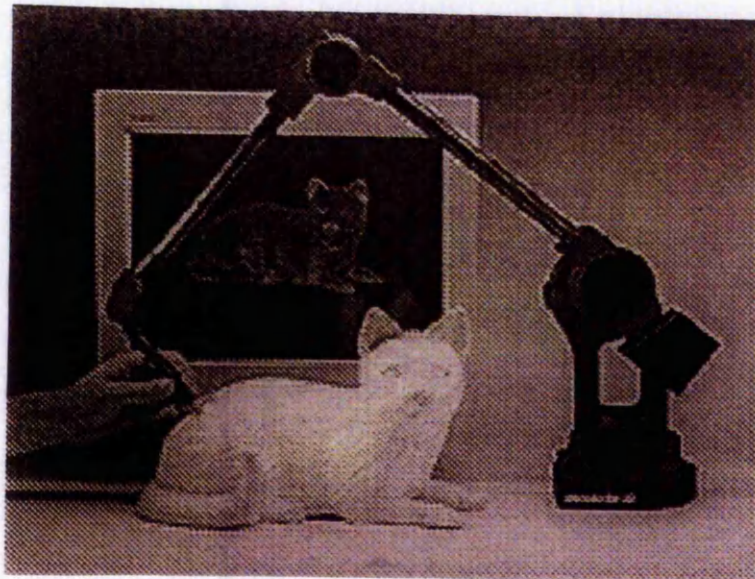
²⁰ The first system 'transmits sound waves and triangulate co-ordinates in 3D space using unsightly and non-portable transmitters mounted to the wall or ceiling', whereas the second system uses 'a magnetic field as the signal medium to triangulate spatial locations' (see 'immerse.com' web page).

²¹ A direct contact with Shen, a post-doctoral researcher in the 'Ecole Polytechnique Federale de Lausanne' in Switzerland (as abbreviated as 'epfl').

Figure 3.4 The general construction of the 3D digitiser



The 'FaroArm' 3D digitiser
(featured in the Faro Technologies, Inc.'s web page, home address at 'www.faro.com').



The 'MircoScribe-3D' digitiser
(featured in the Immersion Corporation's web page, home address at 'www.immerse.com').

This method is widely used in automobile furnishings, shoes, industrial design industries, and in medical surgery. This is because their input objects are usually stable and solid. Despite the fact that 3D digitising can provide accurate data, it is seen unsuitable for live bodies because it is time consuming and the size of the digitised object within an effective work space is also a limit.

An effective whole body scanner, i.e. a 3D non-contact digitiser, therefore, is developed to cope with the specific use, i.e. to collect human body data for size classification, made-to-measure, or 3D CAD application for the garment industry.

3.2.3.2 3D scanning

3D scanning systems usually use light media, e.g. general light or laser, to reflect the surface data of the measured object. Systems usually consist of: a suitable scanning area (i.e. the space for scanning covers the majority of the human body sizes) and an efficient sensor detection device, e.g. cameras or projectors, to access body data in a single pass.

This method of body data collection copes with the needs of non-contact digitising and reduces the measuring time taken to obtain more consistent data. From the sensed raw data to the CAD processed data, the most important consideration is what data solution would be best for garment designers and cutters to start. Hence, to accumulate great numbers of *live* body data, a 3D scanning system should take into account four factors: the live or inanimate factor; the data density requires for use; the device size, measuring ranges, and mobility factors; finally, a manual measure may be required to assist with obtaining the actual measurement in the hidden areas, e.g. the underarm.

It is important to realise that the high data density of the scanning result may show more precise data for the measuring object, whereas it is a handicap when managing high data density in a 3D CAD system. It is therefore acknowledged that an appropriate data density needs to be justified for use in a garment pattern design system.

Cyberware WB4 Whole Body Scanner

'Cyberware', from the United States, has developed the first 3D scanning system since the early eighties. Up to the present, the 'Cyberware WB4 Whole Body Scanner' (Figure 3.5) consists of four scanning instruments mounted on two vertical towers and a fixed platform for the measured object. Each tower has a linear ball-bearing rail with servo control for scanning, so that the measured object does not required to move while scanning. The effective scanning space is 'a cylindrical volume 2 meters (79 inches) high with a diameter of 1.2 meters (47 inches)'²².

The technique used by Cyberware was 'by shining low-intensity laser²³ light on an object to create a lighted profile. A high-quality video sensor can then capture this profile from two viewpoints'²⁴. The luminance or the separated RGB texture of the scanned body surface image could be used for identifying landmarks. Although Cyberware can produce approximately two-million reference points for an entire human body, the final number of data points selected was approximately 340 data points for each cross section (Li, 1997).

Each scan produces high data density and can capture the shape and colour of the entire human body²⁵ in 17 seconds (or less) which almost avoids body sway during scanning.

Uhlig (1996) stated this process:

In 17 seconds a single high-resolution scan of eye-safe laser light, emitted from four scanning heads, captures the shape of the human body. A three-dimensional digital image is built up using separate cameras to record the colour at each of two-million reference points across the body.

The system provides fast body data acquisition, high volume of body data, and high resolution of the scanning solution; however, the cost of the device, approximately \$400,000 dollars (Li, 1997), may have limited its users.

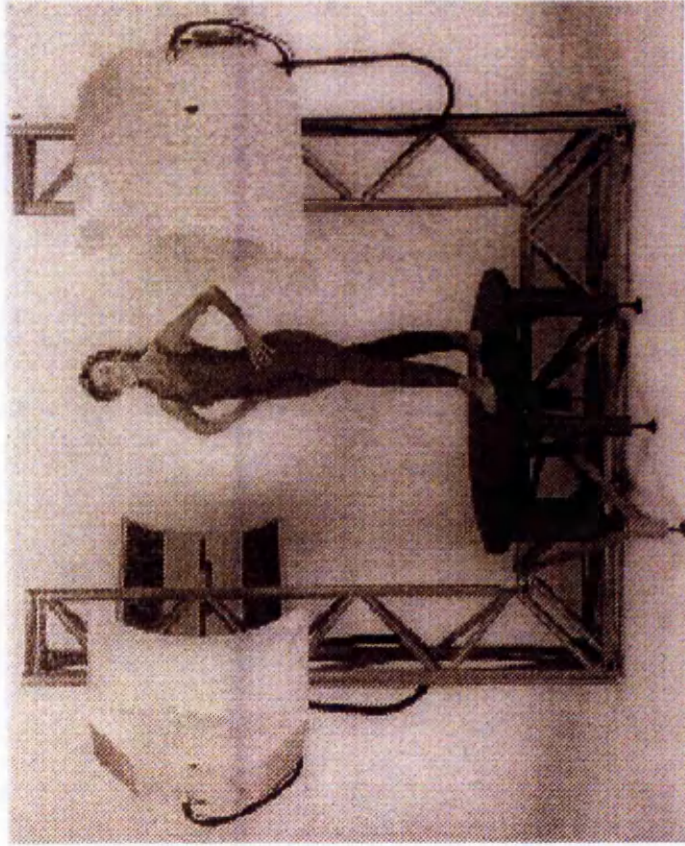
²² at the Web page 'http://www.Cyberware.com/products/wholebody_datasheet.html', pp.1-3.

²³ the eye-safe laser light needs to be under 5 milli-volts, according to US law (private conversation with Dr. Li (1997), who now works for Cyberware and used to be a member of the HUMAG research group (the LASS developer), Loughborough University, UK.

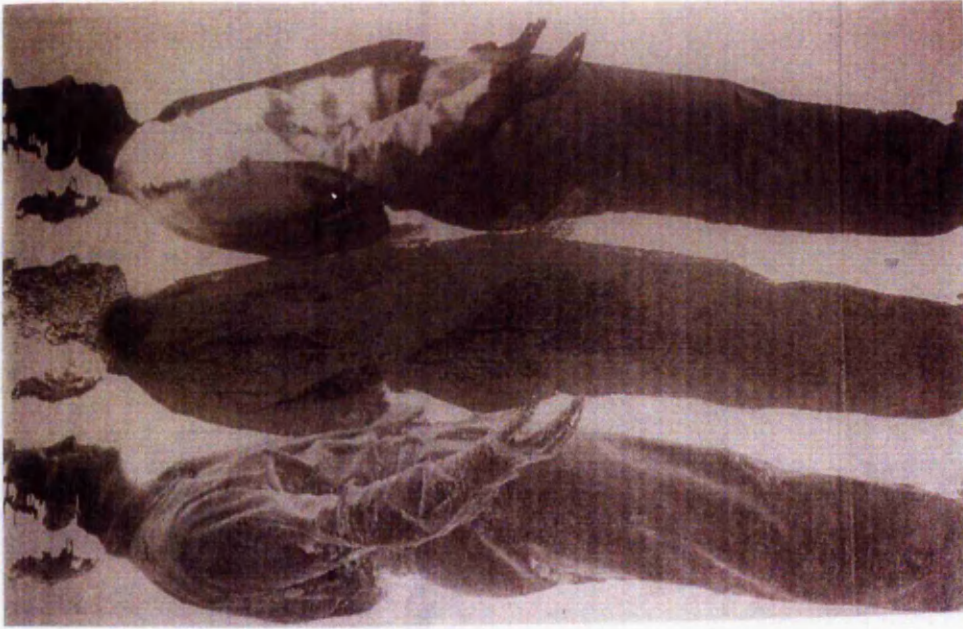
²⁴ at the Web page 'http://www.Cyberware.com/press_release/pr_nurbs.html', pp. 1-2.

²⁵ at the Web page 'http://www.Cyberware.com/products/wholebody_datasheet.html', pp.1-3.

Figure 3.5 The Cyberware WB4 Whole Body Scanner



Cyberware whole body scanner (featured under Cyberware web page, home address: 'www.Cyberware.com')



High-resolution scans can record two-million reference points across the body (featured from the 'Telegraph' newspaper, 6 Aug. 1996)

At present the Human Engineering Division of US Air Force's Armstrong Laboratory uses this system to improve the fit of military clothing and aircraft design (Uhlig, 1996). There are also two other government users, the 'OSHA' (Occupational Safety and Health Administration) and the 'CAESAR' (Civilian American and European Surface Anthropometric Resource) project. The CAESAR project intends to conduct a new body survey, consisting of 8000 subjects in USA and 6800 subjects in European countries using traditional and new 3D anthropometric measuring technologies. It is aiming to produce 50-80 control measurements. The two 3D scanners for this project are the VIRO 3D-2400 whole body scanner²⁶ based in the Netherlands and the Cyberware²⁷ whole body scanner, based in Wright-Patterson's American Air Force Base (Li, 1997). However, cost is still a limiting factor for its use in clothing companies.

²⁶ Details see the near end of this section (p.3-34).

²⁷ Cyberware, the company itself, does not participate in this project

[TC]2's Body Measurement System

The 'Textile/Clothing Technology Corporation' (known as '[TC]2') research team, which is located in North Carolina in the United States, developed this system (Figure 3.6) into the second generation prototype stage in 1996 (Hada, 1997).

The sensed 3D data points are calculated using *phase measurement* (Figure 3.7), i.e. a measurement obtained by calculating the variation between the plane of constant phase from the sensor's projection (i.e. raw data) and the calibration from the CCD camera (i.e. calibrated data)²⁸. A final body figure is represented using the composition 3D data from the six sensing solutions. Butenhoff stated (1997) that 'the system completes the body scan within eight seconds, extracts critical measurements, and utilises software to automatically adjust patterns', but Li (1997) claimed that 'the scanning data contains a greater level of noise, and the data structure may be too big to be transported for further application'. However, Bruner (1997)²⁹ stated that the problem of data collecting noise has been significantly reduced after the introduction of a new device in 1997.

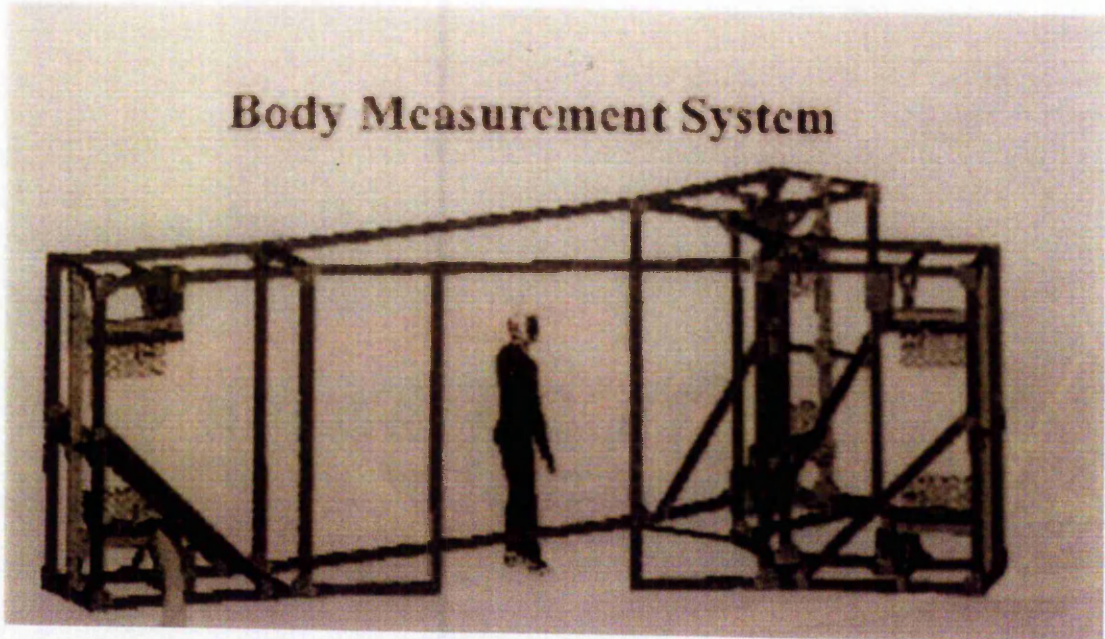
The [TC]2's measuring system³⁰ (constructed in a 'Y' feature) collects about 300,000 data points for a whole body, with '2 mm by 2 mm' data resolution, and processes even faster than Cyberware's scanner (Bruner, 1997). Its 3D scanned data have been adapted to develop made-to-measure patterns by the apparel CAD suppliers such as Gerber, PAD, and Assyst. Clemson Apparel Research, based in South Carolina, adapts not only Cyberware's data, but also the [TC]2's data to develop software for made-to-measure garments (see section 3.5); Clarity Fit Technologies, based in Minnesota, also uses the [TC]2's data to develop made-to-measure garments. Bruner stated that its initial priorities in developing this system were first, retailer-oriented device, e.g. an affordable price for the retailers; second, safety (e.g. using white light instead of laser); and finally, fast scan speed to reduce the inaccuracy, caused by body movement, to a minimum possible. Although the system provides a quicker scanning process (less than 10 seconds), its data density is seen as too intense to be used for this study.

²⁸ at the Web page '<http://www.tc2.com/poster.gif>', p.1.

²⁹ Mr. D. Bruner is the R & D manager in the [TC]2, private conversation, dated 29 Oct. 1997.

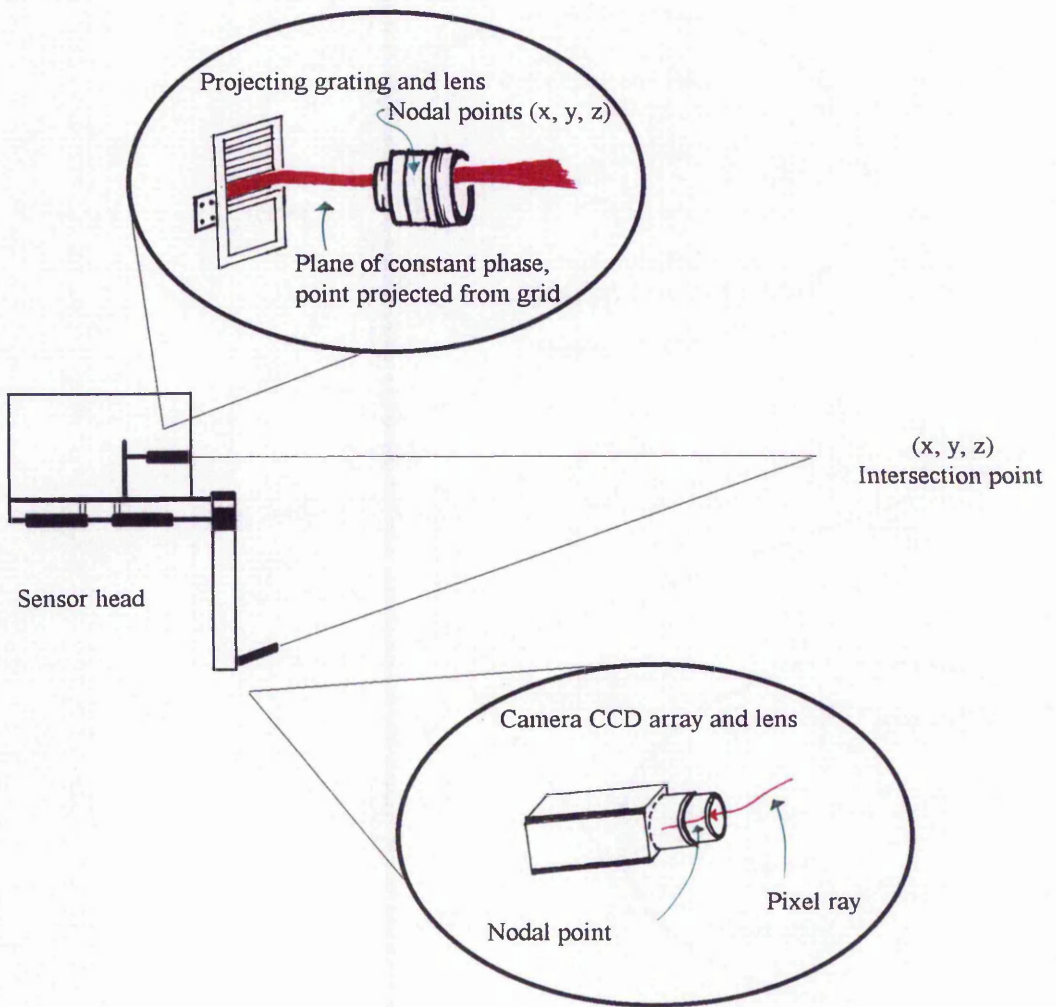
³⁰ Current price (1997) is about \$200,000 dollars, but it is intended to sell for \$100,000 dollars in 1998.

Figure 3.6 The [TC]2's Body Measurement System



Note: This picture was featured in the [TC]2's web page at 'www.tc2.com/poster2.gif'.

Figure 3.7 **The 3D data point is calculated using phase measurement**



This picture has been reconstructed in accordance with the diagram shown in the web page at 'www.tc2.com/poster2.gif'.

Advanced Topometric 3D-Sensor ('Atos')

The non-contact 'Atos' digitising system consists of one projector and two cameras (or 'sensors')³¹ which are placed on one bar. The projection and sensor light form a 45-degree angle to each other (Figure 3.8).

As in the previous two systems, the 'Atos' measuring system also provides high data density (more than 430.000 object points) per view in a few seconds. This may be of great value when absolute precision is required, such as in a medical or mechanical application. However, this does not appear necessary for a CAD generated garment form because high data density, on the contrary, slows down the ease of rotating the CAD generated 3D garment stand or garment form with the processing equipment available.

...existing systems for machine part digitisation produce highly accurate measurements, which are far beyond the requirements in human body scanning. The renunciation of these extreme preciseness offers the potential for the optimisation regarding measurement time and measurement volume. (Tecmath, 1997, p.3) (sic.)

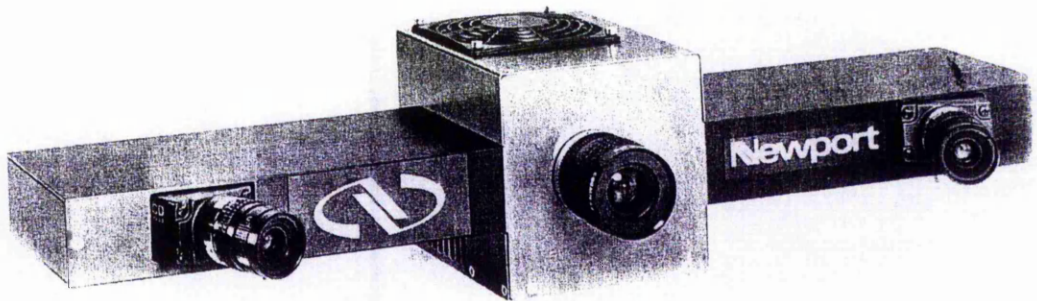
The basic working processes are: first, the projector projects the measured object's surface; then, the two cameras record the surface data from different angles; and finally, the measured solution is 'calculated for each of the CCD camera pixels using the triangulation method and digital image processing'³².

The effective measuring width can be adjusted between 20 mm and 1000 mm. This appears to be insufficient for use for a full body size. Also, it must have limits in collecting data in the unveiled area because the projector and cameras are fixed while scanning.

³¹ The three components are fixed on one bar.

³² A demonstration in the 'Integrating Computer Aided Technology' exhibition ('ICAT', 1996; 1997).

Figure 3.8 The 'Advanced Topometric 3D-Sensor' ('Atos')



Topometric 3D-Sensor for Fast and Highly Precise Object Registration

This picture was featured in the brochure which was provided in the 'Integrating Computer Aided Technology' exhibition ('ICAT', 1997), at the National Exhibition Centre ('NEC') in Birmingham (UK), dated 4 - 6 March, 1997).

The Noncontact 3-Dimensional Human Body Measuring System

Miyoshi (Miyoshi and Isozaki, 1992)³³ was commissioned by NEC³⁴, the Japanese company, to develop this non-contact digitising system. The system consisted of a hexagonal capturing booth with interior dimensions of '150 x 130 x 230' cm and six CCD cameras together with an 'engineering work station'³⁵ (Figure 3.9). It could be developed as a mobile device since mobility would be one of the important features for future measuring systems, as stated by Treleaven and Telmat's sales manager in 1998³⁶.

Miyoshi³⁷ stated that 'the effective scanning domain is about 150 cm height by 65~100 cm width. Six cameras are located approximately 20 cm away from the standing platform level, therefore, the feet and the head are not taken into account in this measuring system'. This could be a limit for use in body sizing because body height is another important guide for classifying body sizes.

This measuring concept also applies the triangulation method (Figure 3.10) which is principally based on the reflection of laser light and the camera's image sensing. Each cross section is 3.75 mm high with 201 sample (i.e. data) points. Because the maximum slices are 400 cross sections, there are more than 80,000 data points used to generate a human body. This system may provide less data density than those systems as stated previously; however, this data density is still an obstacle for its application in this study.

³³ This paper was published in Japanese, courtesy by Lee, an expert in body measuring, in 1995.

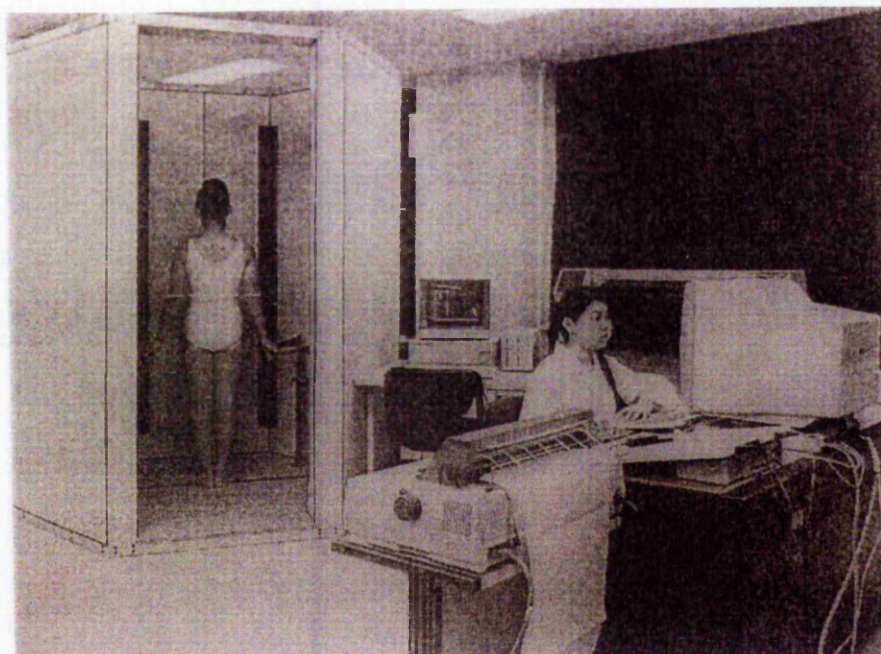
³⁴ in collaboration with the 'Miyoshi research committee'.

³⁵ The peripheral device includes the printer, plotter, mouse, keyboard, graphic display monitor...etc.

³⁶ An event entitled 'Is mass customisation possible?' which was held by the Textile Institute, in Nottinghamshire International Clothing Centre, in the UK (dated 30 Apr. 1998).

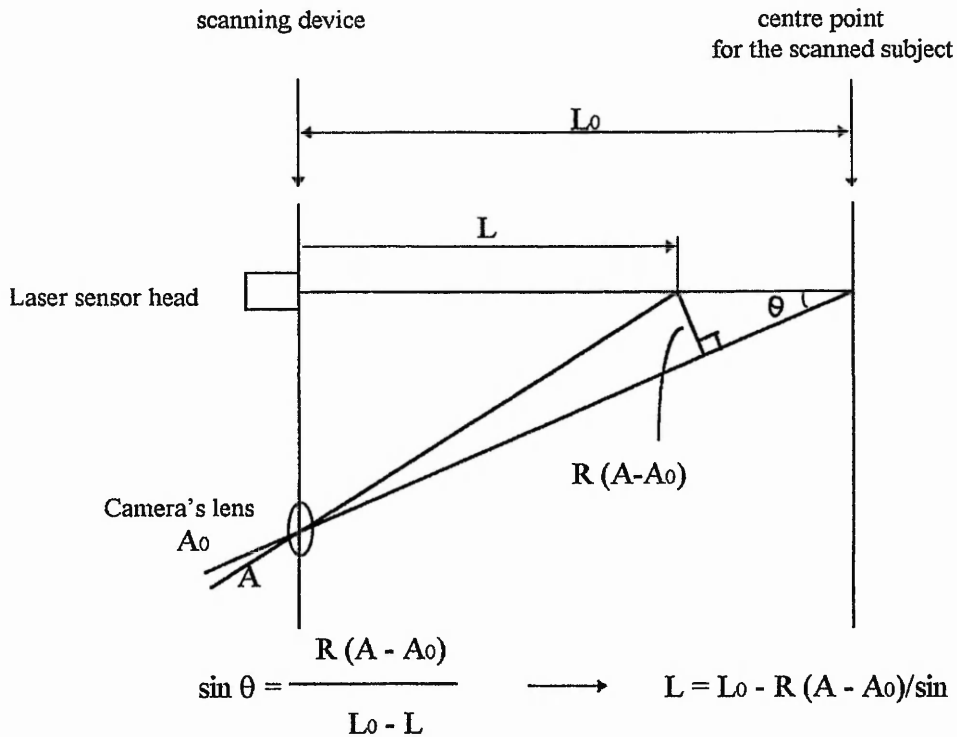
³⁷ A private conversation dated 19 Sept. 1997 (Miyoshi visited the Nottingham Trent University in the UK during 18-19 Sept. 1997).

Figure 3.9 The Noncontact 3-Dimensional Human Body Measuring System



Note: This enlarged picture was featured in Miyoshi and Isozaki (1992, pp.2-3).

Figure 3.10 The 'triangulation method' regarding data acquisition from 3D scan



- L : Distance of the target from sensor detecting.
- L₀ : The base distance from sensor detecting to the centre point of the target.
- R : The multiple of the camera's lens pitching whilst targeting on the object.
- A : The relative data point of the target from camera's lens.
- A₀ : The centre (base) data point of the target from camera's lens.

This algorithm is widely used by today's scanning systems, for example the [TC]2's body measuring system, the advanced topometric 3D-sensor and the noncontact 3-dimensional human body measuring system.

The theory is based on defining the distance amongst the sensor detecting, the camera's lens and the target, so that each angle which is constituted by the sensor projection and the camera's lens pitching can be obtained. By imposing a mathematical algorithm from the known values, the relative distance of the target from the sensor detecting can be calculated, i.e. the data points in relation to a 3D human body or garment stand surface can be acquired.

Note: This diagram was in reference with Miyoshi and Isozaki (1992, p.3) 'The Improvement and the Test of Accuracy on the Noncontact 3-Dimensional Human Body Measuring System' in conjunction with Figure 3.7.

The Tecmath's 3D-Body Scanner

The hardware of the Tecmath's '3D-Body Scanner' (Figure 3.11) consists of a cabin (with an effective measurement volume of '80 x 80 x 210' cm)³⁸ and 4 eye-safe diode lasers with diffraction optics, used in conjunction with software running on a Pentium PC at 100 MHz. Each scan can take measurements at up to '2 x 90,000' per second (Tecmath, 1997).

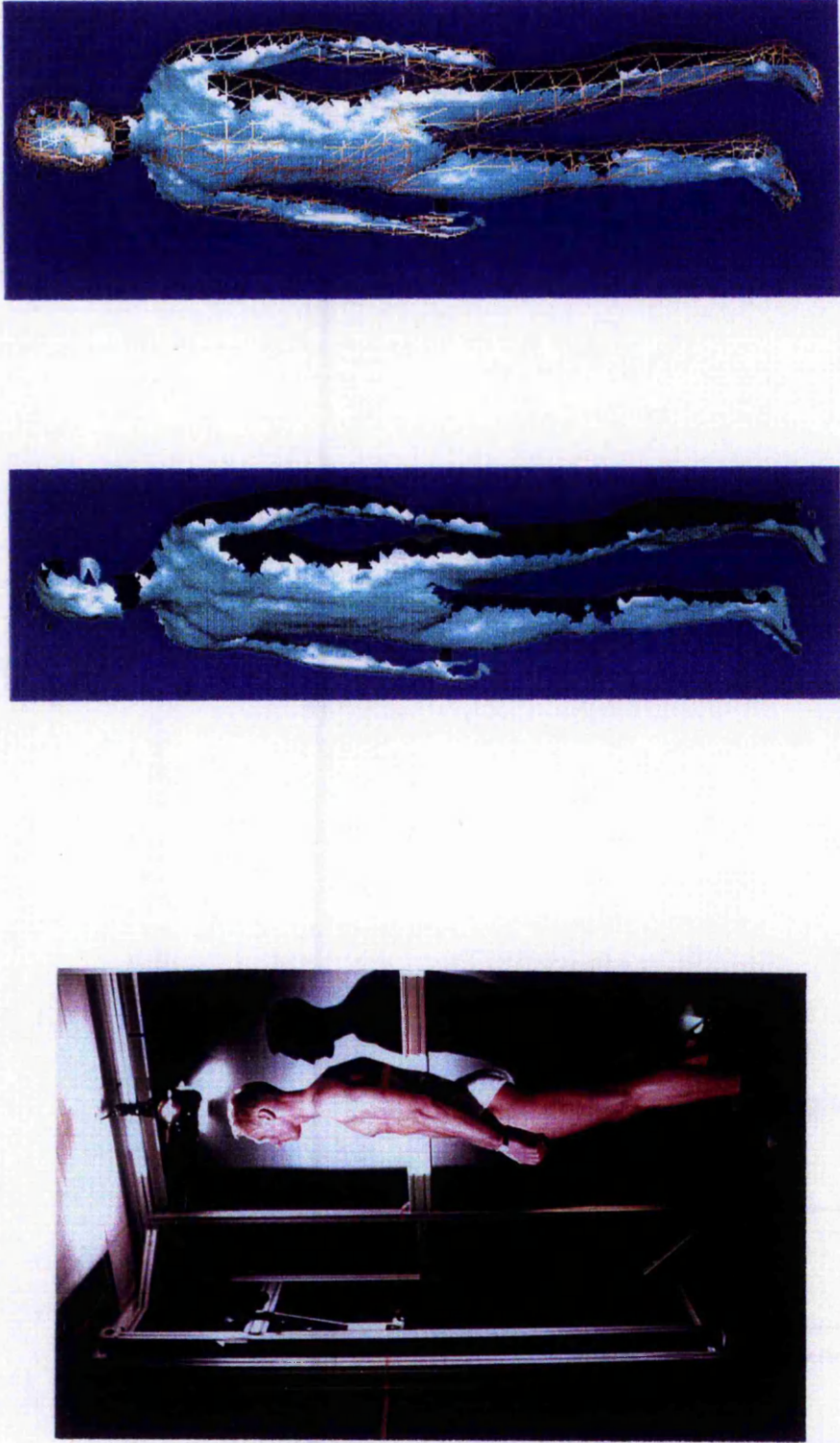
The total scanning time takes only 1-2 seconds for a whole body and it is claimed to be the world's fastest 3D whole body scanning system. However, several tens of thousands of data points may be necessary for a complete body surface. The argument for running these data in a 3D-PDS for design purposes remains.

Tecmath, based in Germany, supplies CAD tools for the ergonomic design of vehicles for the automotive industries. It works as a partnership with Vitronic, a company which is also based in Germany and has developed advanced 3D whole body scanners (see next section). Because of Tecmath's origin, it develops not only the 3D Body Scanner, but a 2D contour measuring system (see near the end of section 3.2.3, Figure 3.14). Both are used in a project entitled 'Production 2000', held in Germany (details see section 3.5).

This appeared to be an early development of linking a 3D digitising system with CAD software in practice, but it was developed mainly for applications in the automotive industries. For use in the garment industry, a direct linkage between the 3D digitising technology and the 3D CAD system is necessary.

³⁸ The construction of the cabin is respectively by '200 x 110 x 280' cm.

Figure 3.11 The Tecmath's 3D-Body Scanner



This picture was featured in the brochure which was provided in the 'IMB' (International Clothing Machine Fair), in Cologne, Germany, dated 3-7 June 1997.

The VIRO 3D-2400 Whole Body Scanner

The VIRO 3D-2400³⁹ is developed by Vitronic, based in Germany, to scan quickly 3D full bodies or living objects. Its measuring method uses the laser split-beam, one of the 3D data collecting methods. The scanner uses a laser line light source with a cylindrical lens and video cameras positioned at a pre-defined angle, i.e. the triangulation method.

This system (Figure 3.12) is constructed as a four-sided cabin with two line lasers and six cameras on each side; each three cameras as a group are located, in parallel, above and below the two line lasers. Each scan, vertically sensed, contains twenty-four images which the total 3D measuring data points for a full body are up to 10 millions, with approximately 1 mm resolution. The measuring process can be completed within 6-20 seconds depending on the desired measuring resolution. The measuring volume of this scanner is approximately 200 x 100 x 100 cm, this means that it is possible to collect two bodies' data in one time.

The VIRO 3D scanner and the Cyberware WB4 whole body scanners will be used for the 'CAESAR project'⁴⁰ because their high resolution of measuring data enables the pre-defined control landmarks to be recognised by the scanner itself.

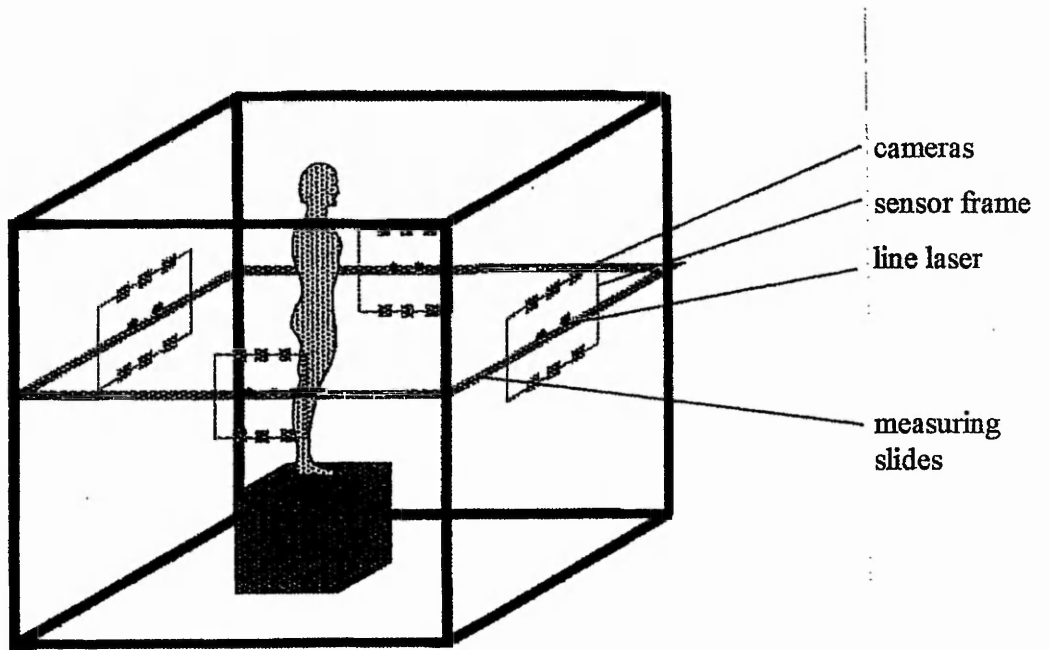
It is true that this scanner produces the most data of all the 3D whole body scanners this study has researched so far. However, this study argues that this data density could be too intense to be viable for use in 3D virtual garment form and pattern design. Although this argument is unresolved at this stage, a cost-effective system, the VIRO 3D-400, has been developed to provide a measuring resolution of approximately 3-4 mm which has not yet resolved the argument.

It is noted that the 3D digitising technique is dedicated, itself, to produce as many 3D data points as possible, whereas this is a constraint for use in the 3D garment pattern design.

³⁹ The net cost for the hardware ranges \$95,200 - 202,400 depending on individual selection (direct contact with Jambor, in the sales department of Vitronic, dated 12 May 1998).

⁴⁰ See 'The Cyberware WB4 Whole Body Scanner' (pp.3-22 ~ 23).

Figure 3.12 The VIRO-3D 2400 Whole Body Scanner



Mechanical design of the VIRO 3D-2400
(reconstructed from the picture which was featured in the Vitronic's brochure)

The Body Lines Scanner (BL Scanner)

This whole body scanning system is aimed at creating a full digital scanning device for custom designed underwear. The hardware of the 'Body Lines Scanner' (Figure 3.13) was developed by Hamamatsu Photonics⁴¹, based in Japan.

The BL scanner uses six pairs of near infrared rays (i.e. sensors) to collect whole body surface data within 10 seconds. It contains approximately 102,400 measuring data points over the full measuring area. The vertical measurement interval, i.e. the cross section, is about 5 mm in height. In turn, each cross section consists of 256 data points over a 2-meter working height (featured in the brochure of Hamamatsu, Sept. 1997).

Dekker⁴², at the University College London ('UCL', UK), currently employs the data obtained from the BL Scanner, with eight near infra-red cameras; first, to build up a simple generic model in order to analyse the human body form and shape for medical or clothing use; second, to generate a surface constructing technique using 25 B-Spline⁴³ control points on each cross section of the scanned body; finally, to develop an automated 'electronic tape measure' which can take body measurements automatically, in the context of garment design (Dekker, 1998).

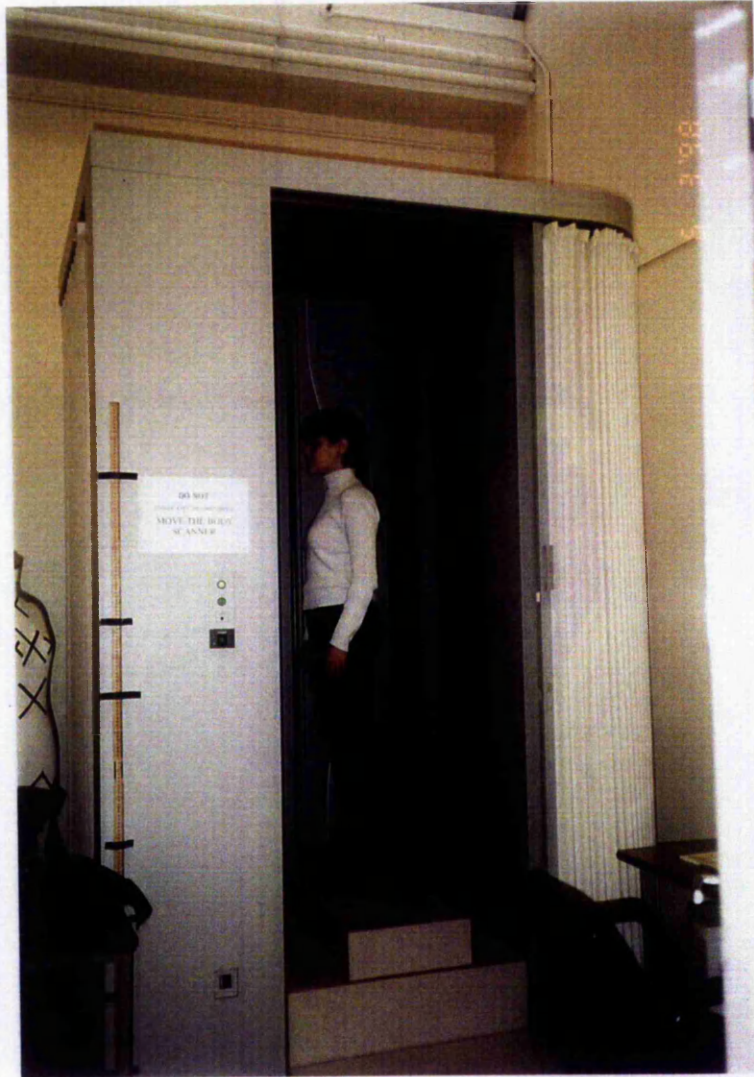
The significance of Dekker's work is: that body landmarks can be located or annotated manually; and that automated body measurements can be obtained, despite a few obvious discrepancies between the manual and electronic measurements. It is not a surprise that one of the most inconsistent measurements is the shoulder length because of the compulsory body stance which will inevitably shorten the 'natural' shoulder length as well as the measurements of the 'mid-shoulder to bust' and 'mid-shoulder to back waist'. However, Dekker's research has made a contribution to a future 3D-PDS by reducing 256 raw data points to 25 control points for each cross section of a 3D virtual body form; the improvement of the automated 'electronic tape measure' is also in progress.

⁴¹ Japanese 'Hamamatsu' company collaborates with University College, London (UK). Direct contact with Dr. P. Treleaven (Dept. of Computer Science, University College, London), dated Oct. 1997.

⁴² Direct contact with Dekker, dated 6 Mar. 1998.

⁴³ One of the mathematical methods of defining a curve for 3D-CAD.

Figure 3.13 The Body Lines Scanner (i.e. the BL Scanner)



This BL Scanner, developed by Japanese 'Hamamatsu Photonics' company, was installed in the Department of Computer Science, University College, London. Researcher Dekker demonstrated the stance of the measured body and how the BL Scanner operated (dated 6 Mar. 1998).

Others: 'converted 3D' whole body measuring systems

The 'converted 3D' measuring systems refer to those in which the process of body data collection is based mainly on using a 2D electronic photogrammetrical technique, but the data can be generated in 3D, i.e. (x, y, z), co-ordinates, with the assistance of an existing CAD tool or model data-based analysis⁴⁴.

This type of measuring system is not a real 3D system, also, its data reliability needs to be questioned. However, compared with real 3D electronic measuring systems, it provides two better features: effective cost and device mobility.

The RAMSIS/CONTOUR measuring system, by Tecmath

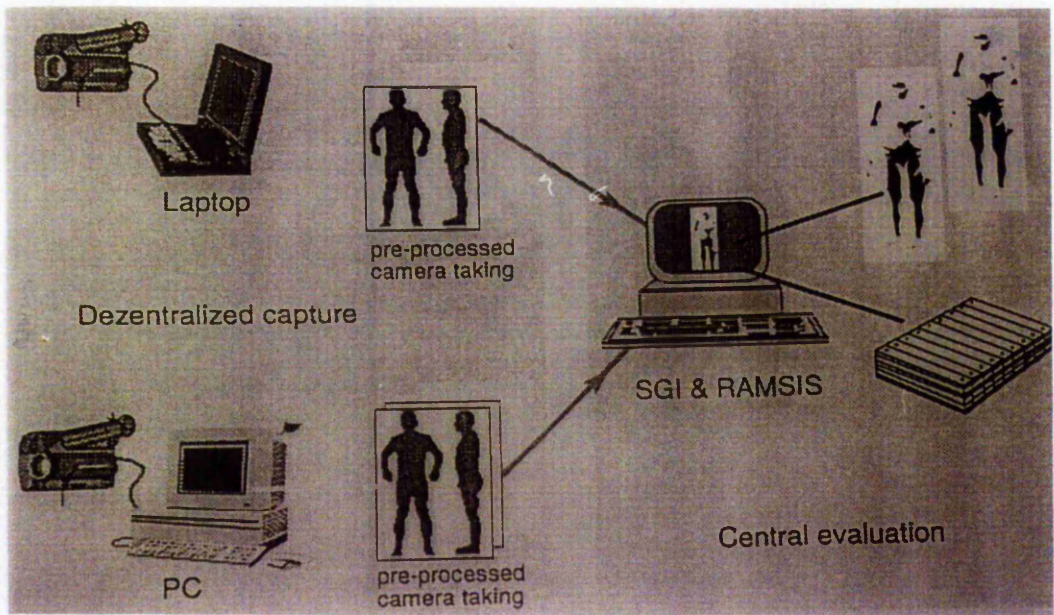
The 'RAMSIS/CONTOUR' (Figure 3.14), is a photogrammetrical anthropometric measuring system. This contour measuring system was developed in association with the RAMSIS, an ergonomic analysis CAD tool for car-clinic.

The acquisition of the anthropometric body construction is divided into five stages. First, capturing the two orthogonal shadow views, i.e. front and profile, of the body. Second, extracting the body contour through the captured photogrammetrical images. Third, adapting the primary body posture with the assistance of the RAMSIS. Fourth, adapting the internal model (i.e. 'skeleton') and the external model (i.e. skin slices). Finally, within 3-5 minutes of processing, either anthropometric data will be available in body dimensions or in a related human model for use in the RAMSIS. It is vital to notice that the employed body adjustments are based mainly on the existing information of the three-dimensional human body which is not developed in the context of garment use.

For the fine adjustment of the selection, intensive usage is made of the anatomy and biomechanic knowledge which is represented within RAMSIS. (Tecmath, 1997)

⁴⁴ An analysis of which relevant dimensional information about a 3D body model has been established by the 2D electronic measuring system, so that a new body model can be measured comparatively with the established body measurements. This often requires several classified models to be chosen, so that the electronic measurements can be kept more accurate.

Figure 3.14 The RAMSIS/CONTOUR photogrammetrical anthropometric measuring system



This figure was featured in the brochure which was provided by Tecmath in the 'International Clothing Machine Fair', in Cologne, dated 3-7 June 1997.

The SYMCAD system, by Telmat

The SYMCAD⁴⁵ (System for Measuring and Creating Anthropometric [body] Database) system (Figure 3.15), is developed by Telmat, based in Soultz, France. This automated body measuring system employs pre-established body models to analyse comparatively with new camera-captured 2D images of the front and side views of the body. The two main groups, i.e. male and female, need to be identified in order that consistent computer calibration can be made. The French Navy first used this system in 1995 to measure soldiers for producing uniforms (Eadie, 1998).

The deficiency of this type of measuring is that it usually collects only horizontal and vertical 'net' measurements using model-based computer calibration. Problems occur where body measurements for basic garment construction are not taken necessarily from a naturally horizontal or vertical condition, e.g. the neck girth, chest girth (for men's wear), elbow girth, and arm length. Beeby (1997) also pointed out the problems which would inevitably exist in this kind of body measurement system. He stated that:

The commercial body measurement system (Symcad) which takes a silhouette picture of the body front and side gives valuable information but the calculated girth measurements do not necessarily correlate with the actual body measure. This software is, however, being modified to improve correlation.

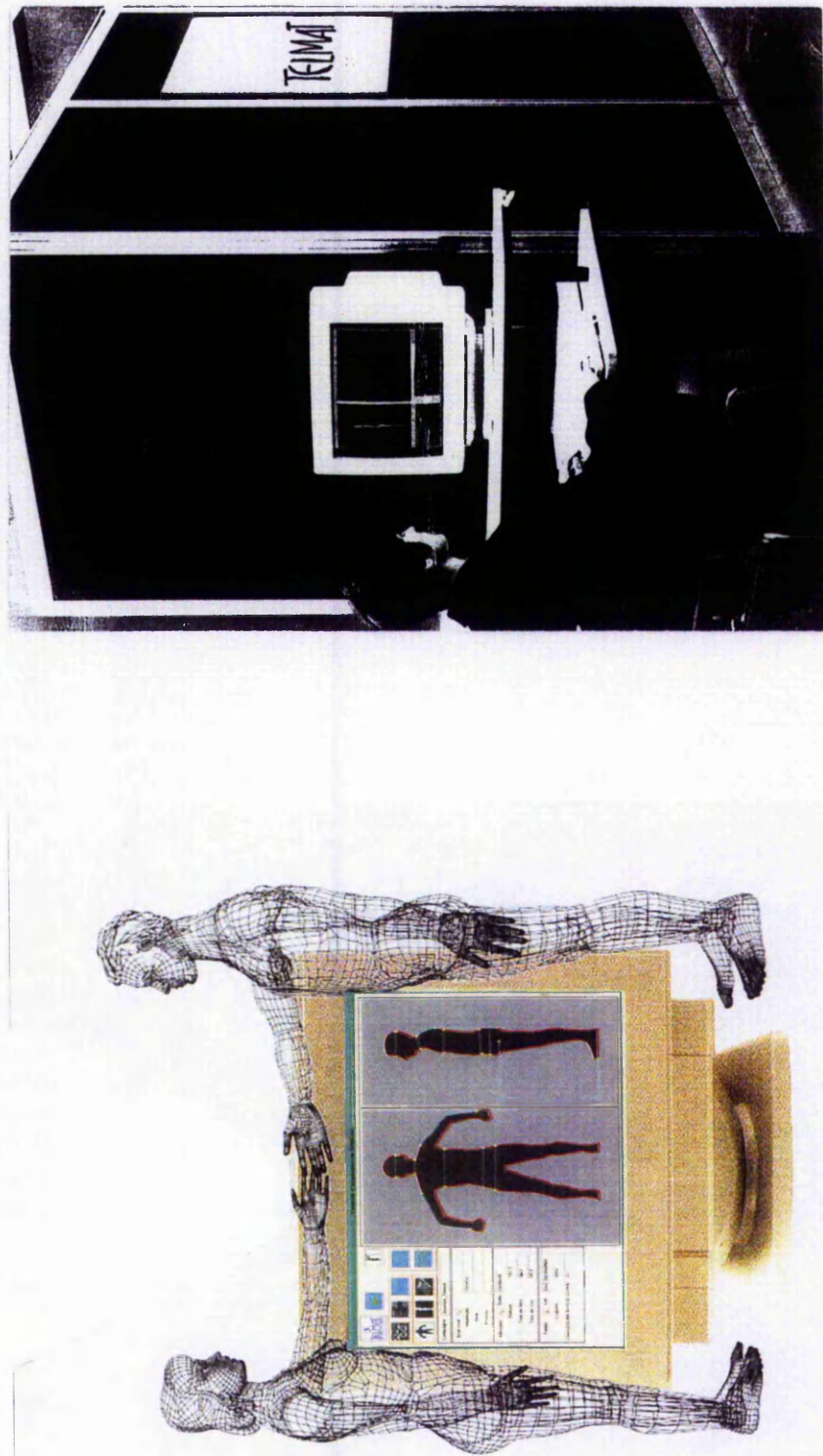
In a 1998 exhibition⁴⁶, entitled the 'BBC Tomorrow's World Live Event', held by the British Broadcasting Corporation, Telmat presented its new improved system the whole of which fitted in a lorry of '400 x 150 x 240' cm. Appendix 15 was an experiment to compare the electronic SYMCAD and manual measuring results. It showed that some results were highly accurate, e.g. the bust, waist girths, and shoulder width, whereas some were not, e.g. the neck girth, ankle girth, and sleeve length. It was noticed that the SYMCAD measuring system did show improvement in measuring a medium build body. A potential application was also attempted to pass the captured data to a Gerber's Made-to-Measure⁴⁷ system linking with a cutter, so that an individual pattern was cut out within

⁴⁵ This software is developed by the French company 'Telmat Informatique' (in the '97 IMB' exhibition, Cologne, 3-7 June; World Clothing Manufacturer, Vol. 75 N. 8, 1994, p.26).

⁴⁶ This was held at the National Exhibition Centre, in Birmingham (UK), dated 11-15 Feb. 1998.

⁴⁷ Further improvement needs to be made in the definition and acquisition of each measurement.

Figure 3.15 The Telmat's SYMCAD measuring system



Left: this was featured in the brochure which was provided in the 'BBC Tomorrow's World' exhibition, in Birmingham, dated 11-15 Feb. 1998.

Right: the measuring booth (this was featured in the 'World Clothing Manufacturer', Vol. 75 No. 8, Oct. 1995, p.26)

a few minutes. Its pattern validity, though, has not been proved because the definition and acquisition of each measurement between both systems were not made consistently. However, this showed the potential of how digital body data may be used in the future.

Having analysed these true or converted 3D digitising systems, it is important to realise that three main areas, in the context of garment use, of applying these digital body data or measurements can be addressed: first, collecting and analysing data into groups of body types so that body sizing can be made more effective; second, individual body data can be used to produce an individual fitted garment by electronic linking, e.g. linking with a network, so that a garment can be made with a better fit; finally, the data collection can be simplified for use in an electronic garment pattern design field, e.g. a 3D-PDS.

For the first application, i.e. body classification or sizing, the data density may need tens or hundreds of thousands of data points to record the body shapes precisely. However, for the other two applications, high data density will become a handicap, not only because it needs expensive powerful computer processing, but because to build up a basic bodice garment form only needs a few control measurements which this study will clarify in Chapter Six.

Despite the fact that there are several 3D body scanning systems available, the EPFL⁴⁸, based in Lausanne (Swiss), developed a method to create a realistic human body form without using 3D contact or non-contact digitising techniques. The simulated 3D human body form was in Wavefront format via a UNIX platform. Although this technique was developed initially to provide tools for the entertainment business rather than for the clothing industry, it may be a good opportunity for application.

Taking into consideration the data density, cost, and geographical convenience, the Loughborough Anthropometric Shadow Scanner (i.e. 'LASS') was selected by this study to collect a garment stand's 3D data. The main reason is that the LASS data can be inputted directly into the 3D software which this study will employ for later experiments.

⁴⁸ i.e. an abbreviation for 'Ecole Polytechnique Federale de lausanne' (Swiss Federal Institute of Technology), direct contact with Shen, dated Feb.-Mar. 1997.

3.2.4 Loughborough Anthropometric Shadow Scanner (LASS)

The 'LASS' (Figure 3.16) is a 3D body scanning system⁴⁹ which was developed by Loughborough University (UK) in the 1980's (Jones, 1993, p.20). The scanner aimed to provide highly accurate 3D measurements of the body for the clothing industry. Data obtained from the body survey using the 'LASS' has been used to produce mannequins by Kennett & Lindsell Ltd. (UK). The result was deemed to be satisfactory by all the manufacturers who collaborated in the project.

3.2.4.1 Device components

The hardware of the LASS consists of several components: a rectangular scanning space; a turnable platform to stand on; fourteen television cameras which are divided into two columns, and each column is placed 6 metres from the other; sixteen light sources in four columns, and each column is placed at the four corners of the rectangular work area.

The effective scanning range is 3 metres from the camera to the centre⁵⁰, i.e. 6 metres in total. The width is not a problem because the platform can be turned, and the data acquisition will only be affected by the distance between the camera and the centre⁵¹.

3.2.4.2 Tasks introduction

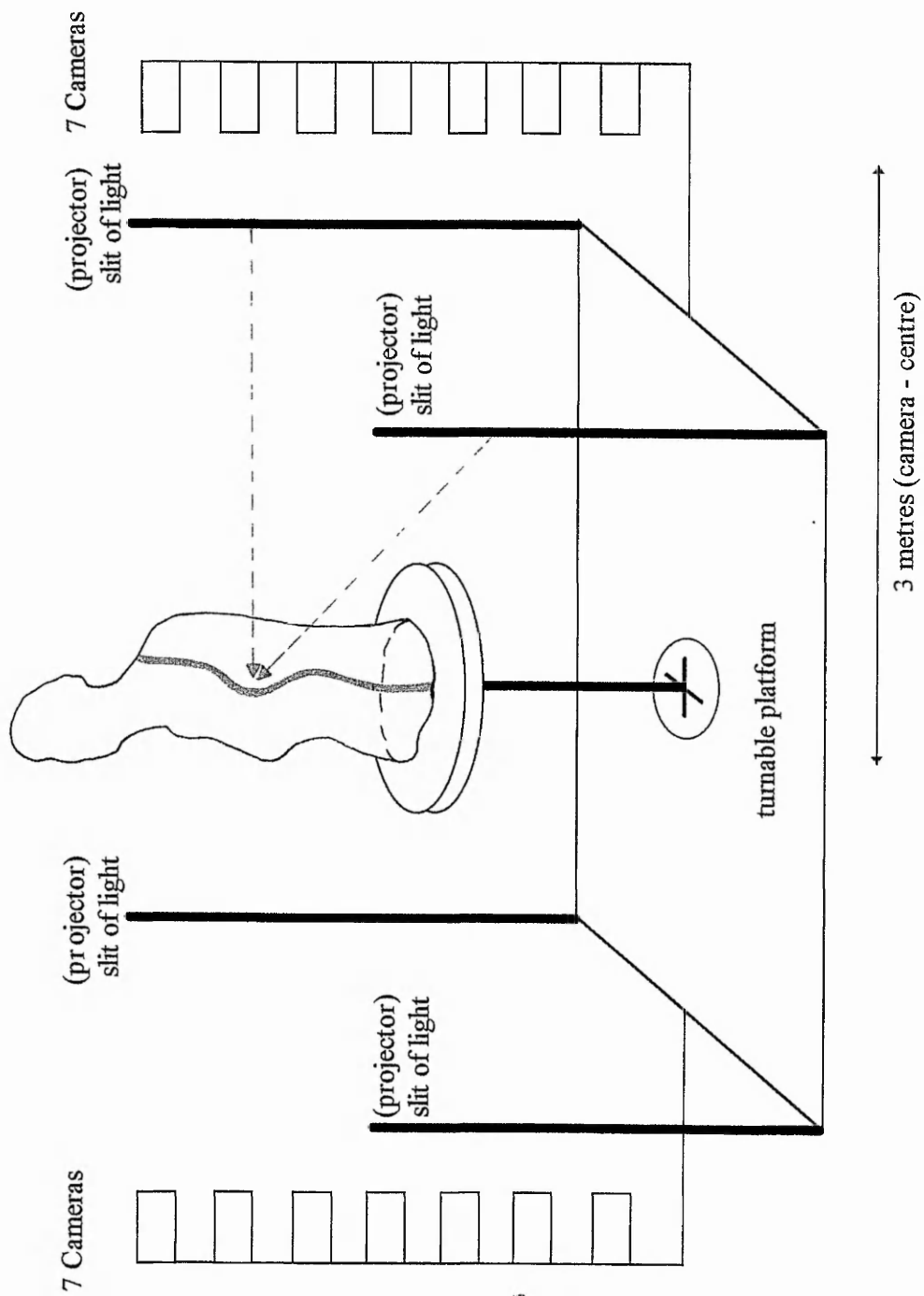
The computerised television 3D measuring system is based on a triangulation method. The subject being scanned stands on a turnable platform and is rotated through 360 degrees and measured in angular increments of 2.4 degrees (Jones et al., 1995; 1993).

⁴⁹ This was a project funded by ACME (Application of Computers to Manufacturing Engineering), and was in collaboration with Marks & Spencer Plc., Courtaulds Lingerie, Kennett & Lindsell Ltd., Bairdwear, Bentwood, Celestion, and Fermark ('*The Development of State-of-the-Art Mannequin*', Apparel International, V 25 N 6, June 1994).

⁵⁰ This is also the place where the turnable platform is located and the measured object is standing on.

⁵¹ Several direct contacts with the researcher Li (in Loughborough University), 1994-7.

Figure 3.16 The Loughborough Anthropometric Shadow Scanner (LASS)



Two slits of light are projected in turn⁵² and intersect on the body in a vertical plane which passes through the centre of rotation. In this way, the measured data provides the 3D surface co-ordinates of a body in a cylindrical co-ordinated form. Each camera can produce 30 lines in parallel to segment at 30 cm intervals, to a maximum height of 210 cm. The height (via the vertical plane at the slit) and the horizontal radii of the body can be easily calculated from the edge of the light slit.

3.2.4.3 Timing and data collection

The scanning process can be completed within 3 minutes⁵³, but the time span for body data collection entirely depends on how much of the total data are collected. A 3D solid body can then be computer generated with a maximum of 420 cross-sections. This means that each cross-section contains 5 mm of the body height. In turn, the total number of cross-sections depends on the height of the input body (or garment stand). Because each angular increment consists of a 2.4 degree angle, the data collected for each cross-section is 150 points. Consequently, the total data for a full bodice length consist of more than 30,000 points. This data density is still too high to execute a viable 3D CAD generated garment stand.

The curve-fitting process was therefore designed to treat the body as a series of horizontal "slices", each of which could be edited in 2-D..... Sixteen data points around each slice are fitted semi-automatically. Manual adjustments are made to remove any spikes of stray reflections (e.g. from hair), to edit out the arms, and to smooth out ripples caused by breathing. (Jones et al., 1993, p.22)

3.2.4.4 Data format

It is noticed that the file format for the obtained data should be suitable for CAD uses, i.e. allowing easy exchange between different hardware and software platforms⁵⁴.

⁵² This is to avoid light interference from each camera.

⁵³ from my personal experience of scanning a garment stand (in full bodice length) using 'LASS', it took '2 min. 38 sec.' to complete the projection, whereas it took '6 min. 10 sec.' to execute the whole process of data collection (dated 21 Feb. 1997).

⁵⁴ Two, commonly used in the CAD domain, are the *IGES* (Initial Graphics Exchange Specification) and

A program has been developed to convert the 'LASS' data to DXF or ASCII format by the HUMAG research group at Loughborough University. This means that 3D scanned data, using the LASS, can be used directly by the CDI-3D software (see section 3.4.2). This development enables further applications of 3D pattern design. Figures 3.17 and 3.18 represent the body forms which are generated respectively by the LASS and the CDI 3D software using the LASS scanning data.

3.2.4.5 The benefits and limits

The benefits of the LASS are:

- (1) It is quicker (than contact digitising) to obtain 3D body data and is compatible with the other software. This has benefits for mass production.
- (2) Its data have been converted to the file specification which can be used directly by the CDI's 3D software.
- (3) Its data density, i.e. 150 raw⁵⁵ data points for each cross section in 0.5 cm intervals, is more than enough to be used in 3D software which later experiments by this study have confirmed.

There are also several limitations which restrict its scope. They are:

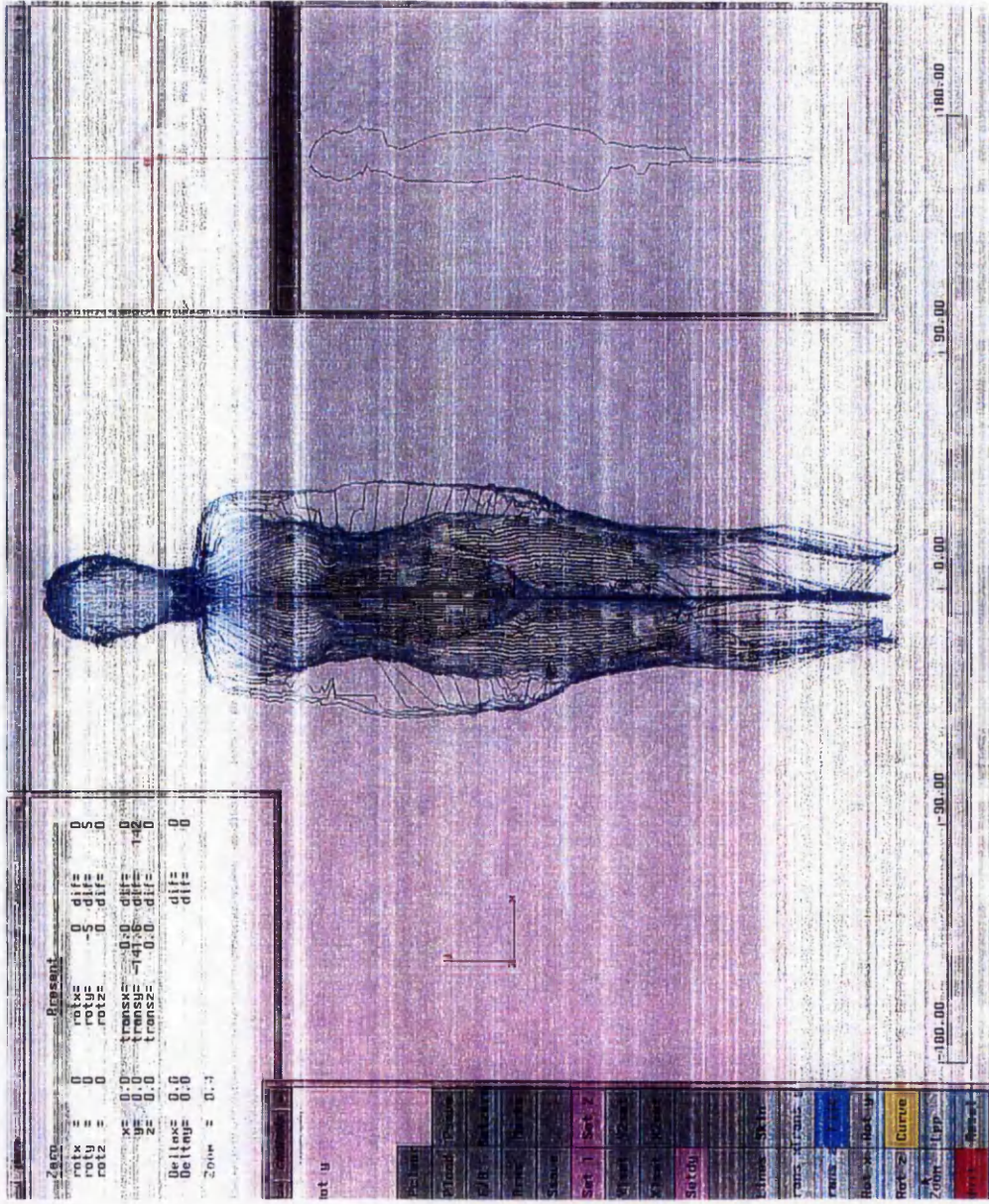
- (1) The constraint of representing precisely the scanned object because the number of control points for the spline is based on a compromise between the ease of editing and the accuracy of fitting one slice of the body. Also, the reliability of stacking of each cross section is questioned, i.e. there could be discrepancy and variations in the body shape.
- (2) the normalisation of the data collection. In order to 'make sense to the scanning device'⁵⁶ and to achieve correspondence between files, the effect of scanning

the *AutoCAD's DXF* (Drawing Interchange File format). However, because of the high volume of the geometric entities, these two methods seemed inappropriate to be used for further application (Jones, 1996, p.9)

⁵⁵ Although it was acknowledged that 150 raw data points for each cross section can be reduced to 16 data points, the original body shape would be questioned. This study chose to use the original raw data in order to avoid any discrepancy caused by shape processing.

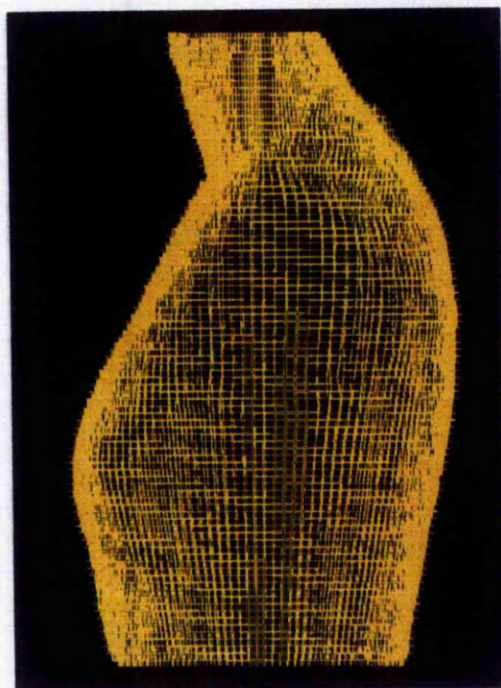
⁵⁶ For example, the measuring object is arbitrarily required to rectify its *normal* stance posture in order to allow the central axis to pass through the neck (Jones et al., 1992).

Figure 3.17 The body form which is generated by the LASS interface software using the 'LASS' scanning data



(courtesy of the HUMAG research group, Loughborough University, UK, dated 21 Feb. 1997)

Figure 3.18 The garment stand (in 'Wireframes') which is generated by the CDI 3D software using the converted 'LASS' scanning data



The 3D scanning data in good scanning result.

posture is removed before comparing body shapes. Inevitably, this could cause a misleading interpretation of the body form and posture.

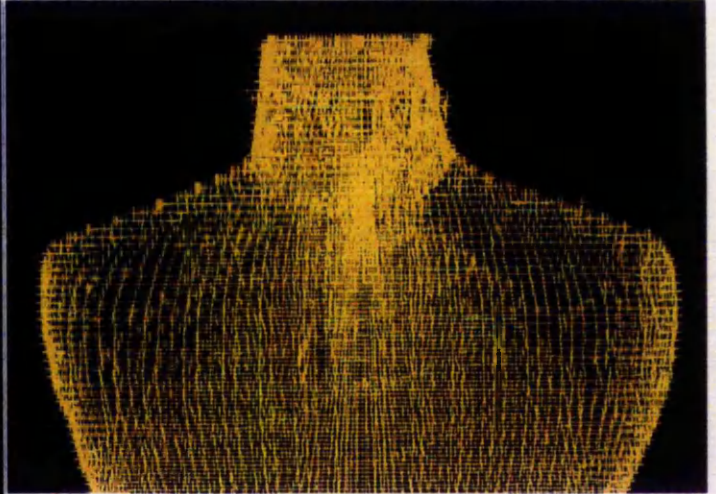
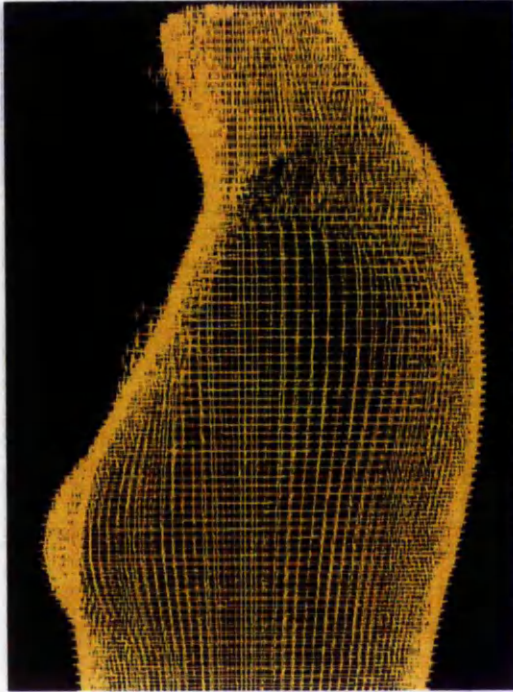
- (3) Rotating the scanned object will make measurements of a live subject unreliable.
- (4) The difficulty of accessing body landmarks while scanning. A photo resistive tape has been tested by this study, but the result showed that 1x1 cm of the tape could not be sensed by the camera, whereas when a larger tape was used that it caused too much stray light reflection.
- (5) Figure 3.19 shows the unsatisfactory data which has been obtained from LASS. The deficiency is usually caused by the stray light reflection of the camera. Hence, great care should be taken to assess the scanned solution. Although it is possible to get rid of stray data points, it is time consuming and care must be taken when reducing or enhancing the original scanned data.

For use in the clothing industry, because garment stands are produced based on an average result of live bodies surveys, non-contact 3D digitising is seen as more appropriate than contact 3D digitising as it takes less time and contacts indirectly on skin. This research investigates the reliability of conversion between 3D form and 2D pattern using 3D modern technologies. For this, there are two factors to be considered. The 3D CAD generated body form or garment stand in the virtual world should be consistent with the form in the real world, and there should be an assessment of the actual conversion occurs in current 3D software's products. Evaluating the first factor requires assessment of the data inputting device, and assessment of the second factor will involve research into garment design and pattern making.

Despite the fact that LASS has limitations particularly related to digitising live bodies, they do not constrain the scope of this study. Because this study primarily aims to evaluate the reliability of the 3D input data, a solid garment stand was selected to avoid the *live* movement factor. This analysis can be seen in Chapter Four (see sections 4.3-4).

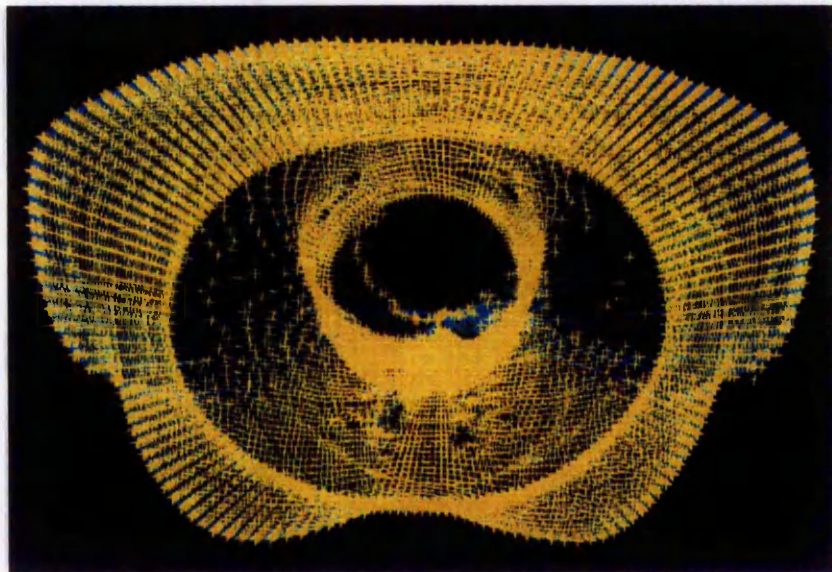
3D data input is an important preparation stage when working in a 3D CAD environment. Having input 3D data, 3D garment pattern design can be investigated further. Prior to this, 2D pattern design is also discussed as it will be linked for use in later experiments.

Figure 3.19 The deficient scanning data



↑ Deficient scanning data (front view)

← Deficient scanning data (side view)



Deficient scanning data (top view)

3.3 2D Pattern Design: Engineering Design

It has been stated that 2D-PDS technique began in the mid-seventies (see section 3.1.1). During the late 1980's⁵⁷, 3D apparel CAD was launched commercially, PDS then became specified as 2D and 3D. In addition, there was also the 2D-PDS with the capacity to show 3D garment form image through simulating patterns 'assembled', i.e. 'pseudo 3D' (e.g. the PAD's '3D Sample', AssyCAD's 'assyGRAPH II', and ModaCAD⁵⁸) or simulating garment drape using 3D grids, e.g. the CDI-U4ia 'Drape' function and Tex-Data system (see Appendix 16). 2D-PDS relates to traditional flat pattern technical needs, e.g. drafting, modifying, grading, lay planning, and storing patterns, but it has limits of interpreting design effectively (see Appendix 17).

3.3.1 2D-PDS

The hardware components a 2D-PDS needs are: a computer; a digitiser or scanner to input the first pattern; and a printer to print images from the screen or a plotter to plot full size pattern. The development of 2D-PDS can be traced back to the seventies (see section 3.1.1). There are more than twenty systems currently available for the clothing industry; better known suppliers are Lectra, Gerber, Investronica, Assyst, and Cybrid. Gerber AccuMark 300, is selected for later linking with the selected CDI-3D system because its pattern files are compatible. This linkage (see section 4.6) is for later transferring the CDI-3D flattened patterns to AccuMark so that pattern comparison can be made.

There are various vector drawing tools in a 2D-PDS, and fundamental functions such as measuring, rotating, and scaling are normally included. However, the main benefit of a 2D-PDS for the garment industry is that it provides a reliable way of transferring and storing pattern data for all seasons, as well as easy access to modify an existing block or

⁵⁷ CDI launched their first release of the 3D software in 1987 (personal contact with Lucinda Pant, marketing co-ordinator of CDI in Grand Rapids, USA, dated Sept. 1997).

⁵⁸ Reference to brochures from the PAD, Assyst and ModaCAD systems.

pattern in accordance with seasonal fashion change. Obviously, the garment pattern making expertise of how to construct patterns in order to make a success of a 3D garment form is not provided in a 2D-PDS program.

Current 2D-PDS may have benefited skilled pattern designers, but this study believes that mastering those electronic graphic tools usually needs much practice and cannot precisely interpret the design in 3D concept due to the lack of information about the form of the body, garment stand, and garment, itself. This limitation often results in an inconsistent posture, shape, and proportion of the body which are ignored in any size classification. Particularly, pattern shapes often vary from one garment style to another, but 2D-PDS cannot cope with this major change. Carr and Pomeroy (1992, p.30) commented:

Standard blocks may be modified to provide silhouettes with only minor input from a pattern cutter. The biggest difficulties arise with radical design changes, where the system has no basis to build on.

3.3.2 Computerised Made-to-Measure System

The computerised 'made-to-measure' was developed to allow the pattern to be drafted more effectively for non-standard sizes. This was created in response to a need to develop a better customised garment in quick turnaround time, i.e. shortening the cycle between retailing outlets and factory production by using computer systems.

Commercial made-to-measure system users in the UK, in the early 80's, were Burton's manufactories at Leeds and Hepworth's (later 'NEXT') at Goole (Turner, 1986, p.55). The fundamental elements for the made-to-measure system were based principally on making structured inquiries of customers to find out their body measurements, specified body form, dictated style specification, and alteration. For example, with GGT's made-to-measure system⁵⁹, body measurements and style features are automatically transferred into pattern grading and alteration instructions and can be processed instantly in the cutting room if the form is completed entirely. Easy data entry and quick processing are the benefit of the this type of system.

⁵⁹ The GGT's video presentation demonstrated in the 'IMB' Exhibition, Cologne (dated 3-7 Jun. '97).

Turner (1986) developed new made-to-measure software for the Burton group and Creations Bridalwear in Wigan (UK). Turner's made-to-measure system for the Creations Bridalwear was 'MicroFit'. Its main structure contained functions, such as, generate made-to-measure patterns, digitise/grade/plot pattern pieces, costing estimate/cut order planning, lay plan, marker and general file management. Ellison⁶⁰ claimed that the system is not only cheap (£2600 for one copy, £600 per extra copy) but also works effectively. Traditional manual pattern making often has 50-60% chance of alteration, whereas this system had less than 5%.

There are other made-to-measure systems available from apparel CAD suppliers, e.g. Lectra, Investronica, and Assyst. The available systems are diverse, the communication between garment and pattern designers are still limited, in particular, the expertise of how 3D garment patterns can be flattened electronically to 2D patterns with shape stability and measurements accuracy. A 3D-PDS appears to offer a solution to this problem.

⁶⁰ A private conversation with Mr. Ian Ellison (technical manager at Creations Bridalwear), dated 14 March 1997.

3.4 3D Pattern Design System (3D-PDS)

Cottis (1991) stated that 'designers must be able to "sell" their designs, and to do this they must communicate their ideas effectively'. Clearly, for garment design, working on 3D form will communicate design ideas more accurately and precisely than even the best 2D drawing. A 3D pattern design system (3D-PDS) for the garment industry would adapt this concept.

The main function of an apparel 3D-PDS is that the 3D computer generated patterns need to be flattened to usable 2D patterns because mass production patterns are still cut in two dimensions. Three essential elements are considered: the flattening from 3D to 2D; the access to 3D garment stands⁶¹ and garment forms; and 3D garment design which help to visualise the 3D concept design earlier in the pre-production stage.

This study considers the issues of conversion of 3D to 2D and the communication between the software programmers and the actual users, i.e. the garment designers and pattern cutters. It is believed that full advantage of modern technologies available for the garment industry have not yet been accepted by garment and pattern designers due to lack of mutual understanding. This study investigated the deficiencies of current 3D-PDS and the advantages of 2D-PDS from a garment and pattern designer's viewpoint to explore new ground for the benefit of the garment industry.

Although several 3D CAD systems are available, the CDI 3D-PDS and Asahi's AGMS-3D (Appendix 18) are the two major players for the garment industry. Both systems have so far not yet convinced potential users in the clothing industry. Even though leading companies, such as S. R. Gent Int.⁶² or MerryMax⁶³, may be willing to use modern 3D technologies, they still await confirmation that such systems are viable from practical evidence.

⁶¹ This is usually accessed by inputting the selected garment stand using 3D digitiser or scanner.

⁶² A direct contact with Mr. London (technical manager from the S. R. Gent International), dated 30 April 1996.

⁶³ A direct contact with Mr. Huang (vice president from the MerryMax bridal co-operation), dated 28 January 1997.

A system structure in relation to 3D garment PDS was demonstrated in Figure 3.3. Fundamentally, the three main components were: 3D garment stand data input, 3D modelling, and 3D garment image. In reality, the electronically flattened patterns in 3D modelling is the core concern. Most of the problems are generated by two variables: the fabric and the garment form. This implies that controlling both variables will be crucial for evaluating electronically flattened patterns for use of garments (see section 4.1.4).

3D-PDS systems currently available usually attempt to perform their superficial garment draping feature (see section 3.5) rather than demonstrate pattern shape stability and prove the electronically flattened patterns. Its efficiency for garment use in practice has not been demonstrated. This is the key reason why potential users cannot be convinced. 3D-PDS for garments is a complex hybrid area which combines crafts and technologies. However, if none of any single case of a 3D-PDS can be proved, there is no point in proceeding further. Therefore, it is realised that demonstrating and confirming the first practical example of evaluating the electronically patterns ought to be the most crucial factor for any future 3D-PDS for garment to which this study will make a contribution.

3.4.1 The 3D CAD systems available

There are several 3D systems available in other industries, for example, the 'AutoCAD, Alias, ProEngineer'. Therefore, it may be worth noting whether they are also applicable for garment use. An investigation into 3D CAD systems available is made specifically in the shoes, the interior & upholstery, and the car design industries because they have the same demand, i.e. 'flattening' a 3D pattern to a 2D pattern, as the garment industry does.

Shoe design

Shoe design has many similarities to the clothing industry, e.g. the use of the 3D 'last' (a wooden foot model) is similar to the function of the garment stand; however, in some cases it is easier to construct a shoe in 3D systems, and in other cases it is more difficult.

Most of the software developed, during the 60's and 70's, was based on standard engineering which was more generic, none of it could cope with the vagary of shoe designs, such as styles, sizes, fits, leather stretch, and distortion while being manufactured flat. These physical characteristics are similar to the human bodice form.

'Shoemaster' was a 3D system specifically developed for designing shoes by employing shoe pattern making expertise⁶⁴. The most applicable function from the Shoemaster for garment design may be the interactive design. This function allows simultaneously seeing 2D pattern alteration whenever any style line is altered on the 3D form. As Paris⁶⁵ (1996) stated that 'to develop a 2D/3D software for a shoemaker requires more attention to dealing with pattern material stresses and strains because shoes usually contain more complex planes within a small area than any others'. This vital requirement has a great similarity to a garment pattern making.

However, most of the materials for shoes, e.g. leather, suede, and plastic, can be bent or formed using an external moulding or pulling force during the manufacturing process. Consequently, examining the discrepancy which occurs in any of these materials on a shoe 'last' would not be comparable to the one for a close fitting garment with a non-stretch fabric. Hence, it was difficult to see its feasible adaptation for garment patterns.

Interior and upholstery designs

It was seen that seating products, e.g. sofas, may have some similarities to the garment pattern making. However, in the exhibition⁶⁶ entitled 'Association Suppliers to the Furniture Industry', the 3D systems demonstrated were for re-modifying an existing 3D form, e.g. DrawPOWER 3D, ArtiCAD and '20.20' Computerised Design which were used mainly for designing kitchen ware. None of the 3D systems showed the viability of flattening 3D patterns to 2D.

⁶⁴ Tony Darvill, who began the 3D concept of developing a 3D computer controlled shoemaking system, was a shoe making master at Clarks Shoes, in Sommerset (UK), during the 1960's (see next footnote).

⁶⁵ I. Paris, manager at Clarks Shoemaster, a direct contact dated 3 September 1996.

⁶⁶ A visit at the 9th 'Association of Suppliers to the Furniture Industry' exhibition, Birmingham (UK), dated 22-26 September 1996.

Automotive design

The CAD packages⁶⁷ used in the automotive and engineering industry are various and popular, the most often used packages are AutoCAD, IBM/CATIA⁶⁸, Alias, UniGraphics, and ProEngineer. The key difference is that a 3D garment pattern will finally be flattened to a 2D pattern, whereas the 'flattening' function in the automotive industry can often be replaced using moulding, bending, or tooling, as with the sheet metal used for car or mechanical industries.

The only application that can be taken from the car design industry may be car seating CAD, such as the 'CDI DesignConcept 3D' used by Callow Maddox and Rover⁶⁹. This is because the material used for a car seat cover is mainly textiles or leather, also it is designed with a seat prototype which is equivalent to a garment stand. Importantly, it provides a flattening program which may have some potential applications.

3.4.2 The 3D Systems Used for Pattern Design

One of the most significant features of a 3D-PDS is to provide a function which can flatten a 3D pattern to a 2D pattern, bearing in mind that the final approval of the electronic 2D pattern for garment use is unproved. This study focuses on the 3D-2D electronic pattern flattening. The reverse path, i.e. simulating natural garment draping feature or 2D patterns 'assembled' to present a 3D garment form type, is excluded in this study as principles and requirements for these two ways of garment pattern cutting are different. The two 3D systems available for garment pattern design are Asahi's and CDI's 3D pattern design systems.

⁶⁷ The visits to the Mar. 1996 and 1997 'ICAT' (Integrating Computer Aided Technology), Birmingham.

⁶⁸ Kayis, B. and Iskander, P. A. (1994, pp.395-7).

⁶⁹ Both companies are based in Coventry, UK. Private visits, dated July and November 1996.

Asahi's AGMS-3D pattern design system

The Asahi Chemical Industry company is one of the major textile manufacturers in Japan. It started its apparel CAD development in 1970, and launched its 3D apparel CAD in the early 90's (Sato, 1990). During the mid-90's 'Bobbin Shows'⁷⁰, the Asahi 3D system became more widely known to the public.

The AGMS-3D system structure (Figure 3.20) fundamentally contains: 2D pattern data input; 2D mesh creation; dummy (i.e. garment stand) edit; 3D co-ordinates edit; 3D pattern data creation; 2D to 3D design; and pattern data transferring (Sato, 1990).

Basic functions are divided into three main sections (Figure 3.21): the '3D File Control' which provides for competency of file management, such as create, retrieve / texture, send, copy, or delete files; the 'Form File Control' which allows modifying, deleting or sending the input 3D form; and finally, the 'Common' which offers competency of changing parameters, backups, and making patterns ('IMB'⁷¹, 1997; MerryMax⁷²).

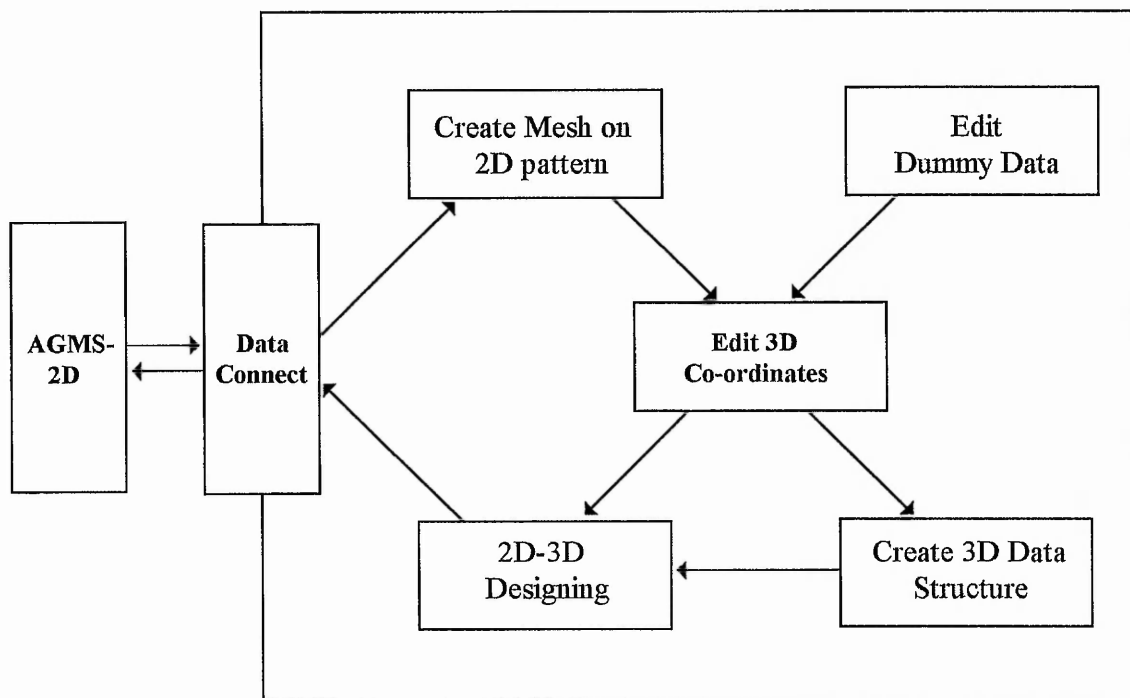
In Figure 3.20, it is clear that the Asahi's AGMS-3D system primarily establishes the 'approval' 2D pattern, then generates meshes for the approval 2D pattern so that the 3D pattern can be recognised and displayed in conjunction with the pre-digitised 3D garment stand. Finally, further pattern modification can be made in accordance with the alteration of the measurements. Without doubt, the 2D pattern shape would have been proved by garment pattern expertise, therefore, there is no point in investigating the 2D pattern shape stability and pattern efficiency for garment use. This is different from the approach at which this study aims.

⁷⁰ A clothing machinery exhibition runs semi-annually in Atlanta, Georgia, USA.

⁷¹ International Clothing Machine Fair, Cologne, dated 3-7 Jun. 1997.

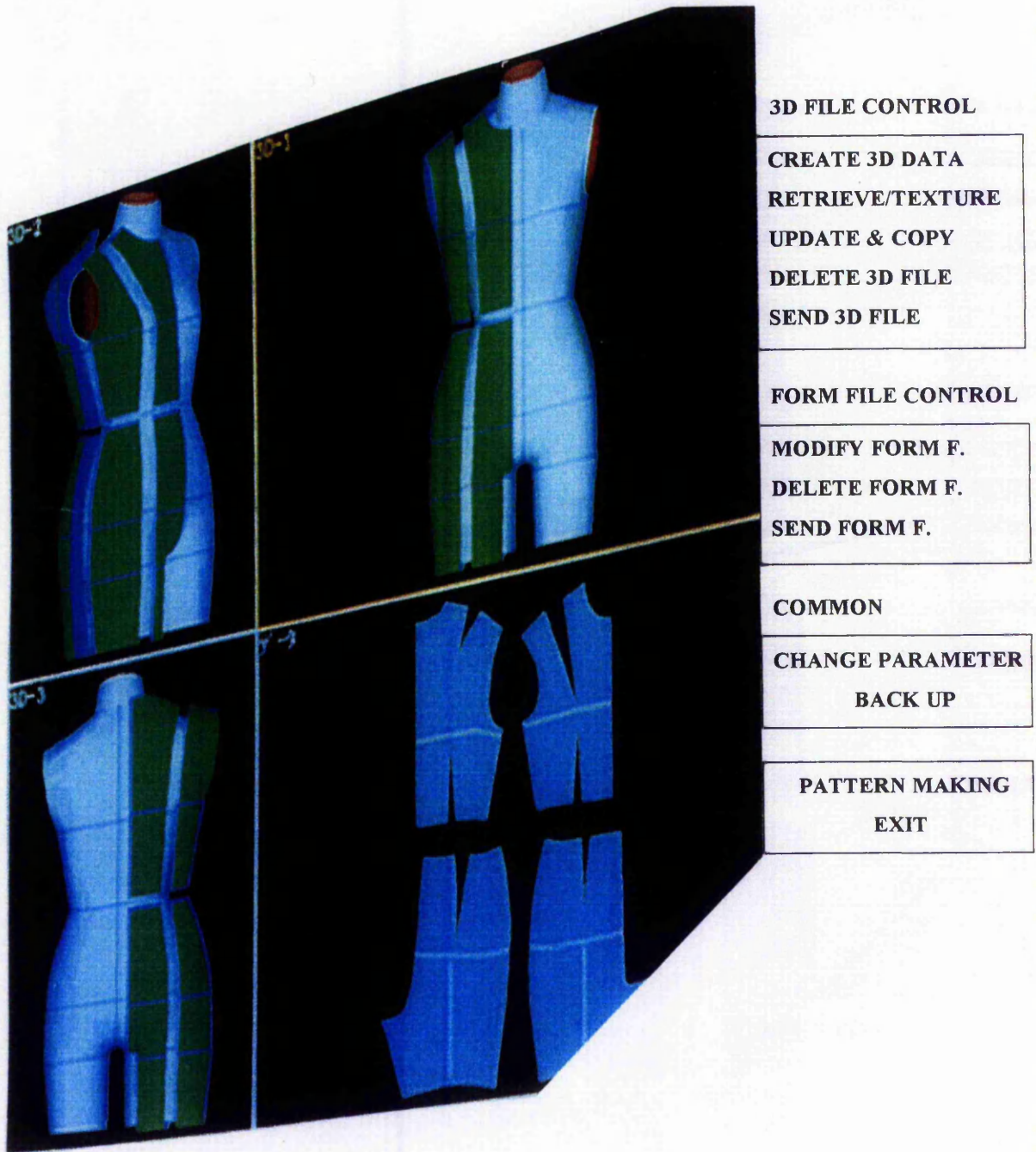
⁷² A bridal wear company, direct contact in Taiwan with Mr. Huang (manager), dated Feb. 1997.

Figure 3.20 The main system structure of the Asahi AGMS-3D software



Note: This diagram was duplicated from Sato, 1990, p.98. Sato is the General Manager of the Asahi Chemical Industry Co., Ltd.

Figure 3.21 The Asahi AGMS-3D system's pattern making function



Left: the picture was featured in Asahi's brochure.

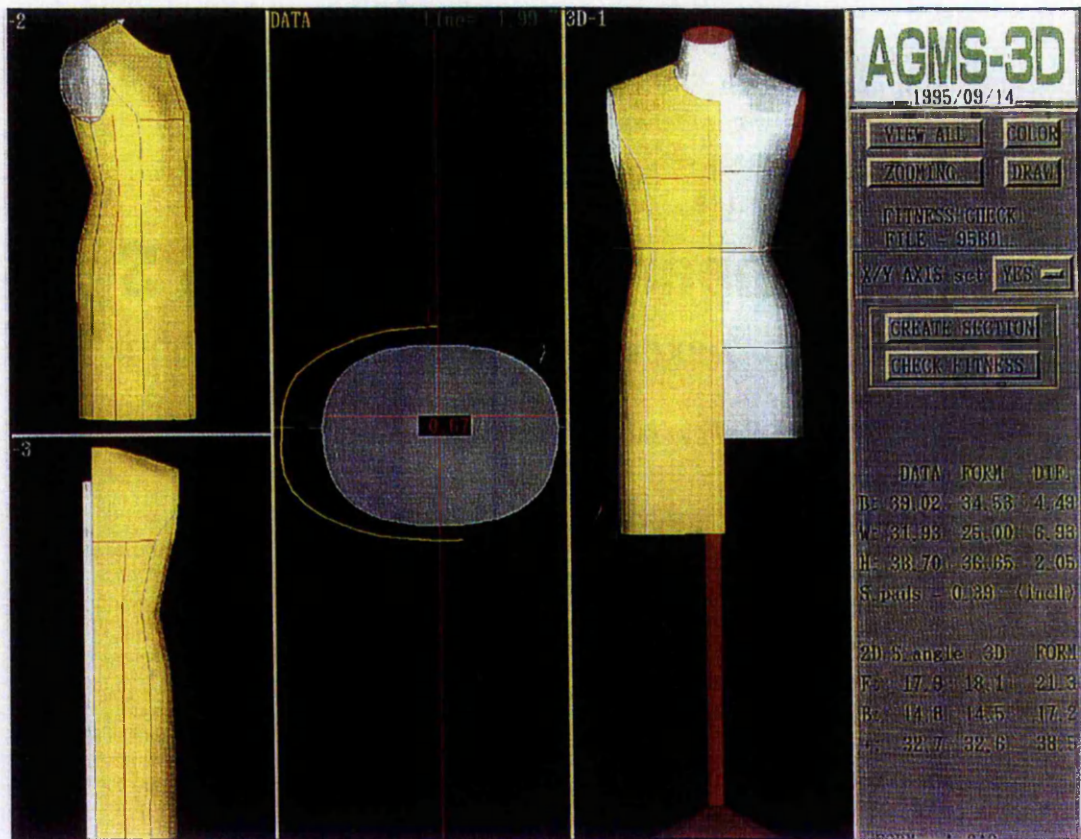
Right: the main functions of pattern making in the current Asahi's 3D system.

The Asahi AGMS-3D system's pattern making function is based mainly on inputting the expected value of the modification in relation to the 'pre-established' garment form type and blocks, and then rectified by three different distributive ratios in accordance with front, side, and back views (see Figure 3.21). This shows the fact that Asahi's 3D system has less competency in executing design three-dimensionally in real-time because it only provides basic angles of views, such as front, back, and 45-degree side views.

It is also worth noting that there are two functions which are highlighted both by Asahi and CDI. One is that it checks the fitness of the 3D garment form in relation to the garment stand (Figure 3.22), and the other is that it displays realistic 3D image using KES (Kawabata's Evaluation System for Fabric), i.e. visualising a 'draped' garment form (Figure 3.23) by imposing simulations for real-time static fabric drape together with a mapping technique (Hardaker and Fozzard, 1998). These two highlighted features, i.e. fitness check and draped garment, address the importance of the fabric variable employed because fabric draping ability will dictate the visual and technical consistency of the 3D electronic garment patterns. Consequently, in order to focus only on the pattern matters, the fabric variable needs to be stabilised.

With the AGMS-3D system, the concept of 3D pattern design is still limited because the 2D pattern shape is proved before 3D modelling, the pattern design lines cannot be constructed in three dimensions, and it does not clearly identify whether it is a modification to the ease distribution or to the garment form, itself. It is necessary to investigate another available system, i.e. the CDI-3D system.

Figure 3.22 The 'fitness' check between the garment stand and the garment form



This picture was featured in Apparel International, December 1995, p.36.

Figure 3.23 The 3D garment visualisation using 'draped' garment patterns



This picture was featured in Asahi's brochure in the International Clothing Machine Fair, in Cologne, dated 3-7 Jun. 1997.

CDI DesignConcept 3D system ('CDI-3D')

The CDI DesignConcept 3D (CDI-3D) software was developed by 'CDI Technologies Inc.', based in Grand Rapids, USA (previously 'Computer Design Inc. '), but was taken over by Lectra in Spring 1997. CDI also developed a leading-edge⁷³ 2D concept design system, i.e. U4ia, which can work interactively with the 3D system. This has a potential feature for the visualisation of a garment design in conjunction with a realistic fabric. Fundamentally, the major solution is about obtaining a 'contact-fit'⁷⁴ (i.e. skin-off) pattern from a 3D form surface (see Figure 5.1, p.5-4). The main procedures of the CDI-3D system to design and cut a garment pattern can be identified as five major steps.

First, obtaining a garment stand is necessary because the curvatures of a garment stand are too complex to be constructed simply using (x, y, z) 3D co-ordinates. This is done by 3D contact or non-contact (see sections 3.2.3.1-2) digitising techniques. The obtained 3D data points are generated as a garment stand form by means of 'Wireframes' (see Figures 3.18-19, pp.48-50). Modification to the garment stand data can be made through a 'Resize' program, but it requires to re-size consistently the selected Wireframe in accordance with a selected position. This can offer only a proportional modification rather than an individual requirement about the type of the most expected garment stand.

Second, the 'Surfaces' program (Figure 3.24) is used to generate a concrete 3D garment form surface for placing style lines. Importantly, by doing this, thousands of 3D data points for the garment stand are reduced significantly (see section 4.3.2.3, p.4-25). This technique is often in connection with 'shading', 'render', 'light', and 'raytracing' techniques (Appendix 19) to help visualisation. At this stage, the generated garment stand becomes solid, so that its form type, posture, shape, and proportion can be manipulated to meet individual demands.

Third, the 'Curves' program (see Figure 3.24) offers different types of curve lines which enable style lines (i.e. 3D patterns) to be drawn onto the garment form surface. This

⁷³ The 'CDI users meeting in 1996', in the UK, had more than one hundred people from major textile design companies, such as Courtaulds and Coates, who could justify this claim.

⁷⁴ A 'skin-tight' fitting type, i.e. theoretically, no ease exists between the fabric and the form surface.

Third, the 'Curves' program (see Figure 3.24) offers different types of curve lines which enable style lines (i.e. 3D patterns) to be drawn onto the garment form surface. This technique is done by using NURBS (Non-Uniform Rational B-Spline), a mathematical method of dealing with constructing curved lines in a CAD environment.

Fourth, the 'Regions' program (see Figure 3.24) is used to flatten the 3D patterns to 2D patterns by which 'finite element analysis'⁷⁵ (i.e. 'FEA') model is used to analyse the stress and strain between the 3D and 2D patterns (see Figures 5.1-2, pp.5.4~5). Some parameters are used to assist in enabling a 3D pattern to be converted (i.e. flattened) to a 2D pattern with some distortions; the changes of the pattern edge measurements and areas can also be calculated by this parameter-based flattening process (see section 5.2, 'Background to the experiments', pp.5-3~7).

Finally, the 'Draping' module (Figure 3.25) refers to 'the process of seaming 2D pattern pieces together and draping them over a 3D model, such as a mannequin'. This function 'simulates gravity in the negative Y direction' (CDI, 1995). This technique is excluded from this study in order to focus on '3D-2D' flattening.

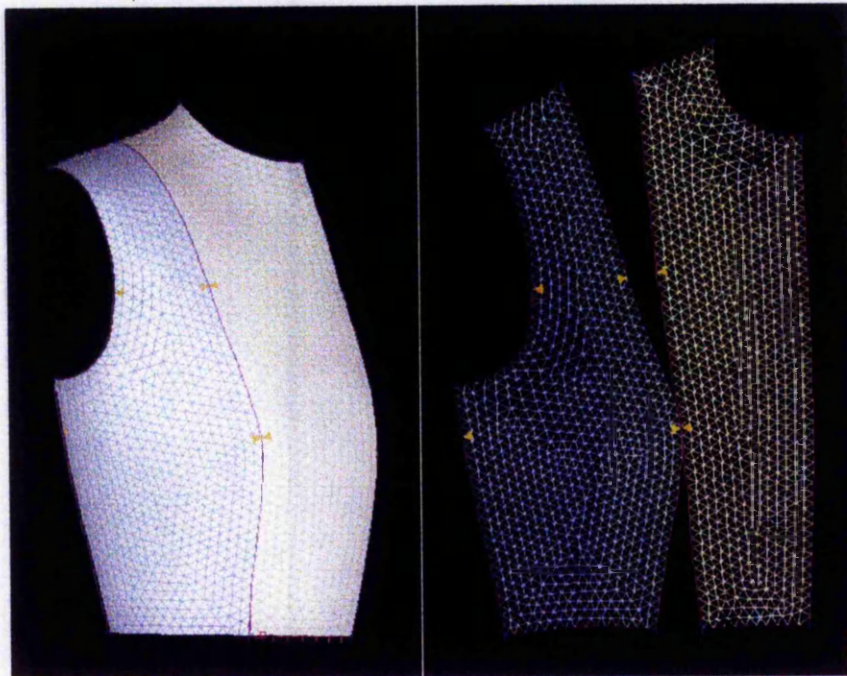
In these five major programs, particularly during the flattening ('3D-2D') process in the 'Regions' program, parameters for flattening a 3D garment pattern have not been clarified. This parameter-based flattening method can produce a 2D pattern shape with some distortions; its pattern edge measurements may possibly be controlled to be as identical between 3D and 2D patterns, but its flattened pattern shape stability is either unclear or uncontrollable. This needs to be investigated further using a real garment case.

It is also generally understood that software is expected to update (i.e. make progression) from time to time; however, the CDI-3D software from release 5.1 to 5.2, despite cutting down 1-2 processes when flattening a 3D pattern, did not make a significant progression in terms of solving the problems of electronic pattern distortion. Yet, one program (e.g. 'Flatten') overlapped the other (e.g. 'Regions') which limited computer memory for use.

⁷⁵ This model 'divides the surface of a piece of fabric into a grid and then mathematically figures the curvature of the surface based on the qualities of the particular fabric in question' (Nannery, 1996).

Figure 3.24

The 'Regions' module in the CDI-3D system



The triangular meshes in left image demonstrate the '3D region' which has been generated a 'Surface' with 'shading' techniques.

The triangular meshes in right image demonstrate the '2D region'. The yellow triangles are the 'landmark' technique.

Figure 3.25 The 'Draping' module in the CDI-3D system



This picture was featured in the CDI-3D system which this research used.

3.4.3 The Limitations of Current CDI-3D System

From the published papers searched, it remained unclear whether the flattened pattern shape, area, and edge measurements can be approved by garment pattern expertise.

The Regions program applies the 'finite element analysis'⁷⁶ to estimate a 2D pattern's geometric shape and the stress and strain analysis. Automative user, Ridgway⁷⁷ claimed that the approval of the flattened 2D pattern in the application of car seats could be up to 95%. This would be less if it is applied for flattening a more curved form, e.g. a close fitting garment form. Another user, Pfeiffer⁷⁸ has successfully used the system for underwear. However, it can be argued that a bra is typically a particular 'dual bending' form whose style line is often constructed through the most prominent point (whereas garment style line is varied); there were more than three 'cuts' on the bra pattern, in Pfeiffer's examples; also, the chosen fabric had a stretching ability.

Remember that a garment stand's surface is different from a close fitting garment form's (Figure 3.26). The first is usually for the use in foundation garments such as bras. The second is for the use in the outer garments, such as blouse or jacket. The 'ease' is the vital factor to be controlled in this context. Also, the surfaces need to be defined as inner or outer surface. Current CDI-3D has not yet addressed this problem fully, so that its viable application for garment use is still unproved.

The CDI-3D may provide an option to produce consistent pattern peripheries between 3D and 2D, but it is impossible to obtain the same pattern edge measurements and areas between 3D and 2D because any 3D spherical surface cannot be flattened to 2D without distortion (Heisey et al., 1988; Okabe et al., 1992). This is the key constraint which is bound to exist in mathematical computation, alone. Hence, it is deemed that garment pattern cutting expertise needs to be employed to compensate for this deficiency.

⁷⁶ This model 'divides the surface of a piece of fabric into grid and then mathematically figures the curvature of the surface based on the qualities of the particular fabric in question' (Nannery, 1996).

⁷⁷ A car seat designer in Callow Maddox company, Coventry, UK (private visit, dated 31 July 1996).

⁷⁸ Direct contact, during the '97 IMB exhibition' in Cologne (Germany), dated 3-7 June, 1997. Miss Pfeiffer, researcher in the Textile Research Institute based in Greiz (Germany), can be contacted by Fax. (49)-3661 611 222.

Figure 3.26 The difference of flattening a garment stand's and garment form's surfaces: the 'ease' factor



This figure is a side view of a cross section of the two overlapping images: one is a net garment stand form and the other is a garment form with an ease padded on the garment stand. The first is demonstrated using 'Wireframes' (the yellow data points in the picture, see section 3.2.4.5, Figures 3.18-19), and the second is demonstrated using a shaded surface (see Appendix 18).

The 'hollow' parts between the net garment stand and the padded garment form demonstrate the 'ease' factor in close fitting garment form which is significantly beyond imagination.

It is generally understood by mathematical experts that a 3D formed pattern will never be the same as a flattened 2D pattern, as stated by Heisey et al. and Okabe et al.

'A spherical surface cannot be mapped onto a two-dimensional surface without distortion, that is, stretching or compression the distance between points on selected areas of the surface'. (Heisey et al., 1988, p7.)

'There is no guarantee that the developed 2D pattern will take the very indicated 3D form because the cloth is no more constrained on the indicated surface in the natural draping process. In other words, there are 3D forms that can never be realized by draping. (Okabe et al., 1992, p.110)

This inevitable mathematical limitation causes a critical problem: there is no criteria for a pattern designer to assess the flattened pattern. Although Hinds et al. (1992) believed that any defined pattern shape on the 3D garment stand could be obtained by the equivalent 2D patterns, they also acknowledged the fact that:

The curvilinear dimensions will be determined by the dimensions of the body. It is possible therefore to develop or flatten the 3D shape to obtain the equivalent 2D cutting pattern. This is a common problem occurring in many fields such as sheetmetal work, shoe making and shipbuilding. Depending upon the degree of double curvature and the type of curvature, some adjustments must be made for plane 2D materials to fit 3D surfaces. (Hinds et al., 1992, p. 11).

Therefore, when applying 3D technology for cutting a garment pattern, problems will occur in: first, discrepancy tolerances of the pattern edge measurements and areas between 3D and 2D patterns; second, unstable 2D pattern shapes (practical experiments can be seen in section 5.4). This problem will be named as *electronic pattern deficiency for garment use* in this study.

3.4.4 The Potential Advantages of Current CDI-3D System

There are three reasons which explain the selection of the CDI-3D for later experiments. First, it provides the 'flattening' function which enables the evaluation of electronic pattern efficiency for garment use to taken place. Second, the most valuable integration for application here is its ability to link directly with the Gerber AccuMark 2D-

PDS (see Chapter Four, Figure 4.25) which is a standard industrial garment CAD system (see section 4.6). This enhances further applications in the pattern modification and verification. Finally, the feasibility of establishing a 3D garment stand using 3D (contact or non-contact) digitising data. This solves the difficulties of constructing a 3D body form directly using (x, y, z) co-ordinates. In addition, CDI also developed an advanced 2D concept design system, i.e. the 'U4ia', whose potential applications may be extended in the future.

Summary for the 3D CAD systems available

3D CAD systems available for other relevant design industries cannot satisfy the requirements for garment pattern design. This is because the 3D CAD generated garment form will be finally flattened into irregular 2D pattern shapes, whereas the demand for flattening the 3D form in other industries is either rarely needed or, more often, their 3D form consists of larger or simpler planes. This was understood long before the invention of CAD system, as stated by Morris.

In engineering, mechanics or architecture, scientific calculations may be applied to the working out of problems; in these instances the objects under survey are definite dimensions and constant in shape. (Morris, 1932, p. vii)

Amongst the 3D systems stated previously, Asahi 3D system was abandoned because it is constrained in constructing style lines in a continuous condition; the CDI-3D system showed the best potential to be used for this study. Because the CDI-3D system offers a flattening function, it allows the electronic pattern shape stability and pattern efficiency for garment use to be examined if some conditions in the real world can be controlled identically as the conditions in the virtual world (see Chapter Four). The specifications of the CDI-3D software used in this study stated in section 3.6 (p.79).

3.5 Related Academic Research

The related research areas are diverse, but most of them are focusing on simulating fabric drape which is divided into 'dynamic' (Stylios et al., 1995/96; Imaoka, 1996) and 'static' (Matsuura in Hardaker and Fozzard, 1998) drape, such as when transmitting the 'concept' drape⁷⁹ to the 'engineering' drape⁸⁰. Many researchers have tried to fulfil the requirements for computation, e.g. the 'finite element'⁸¹ method by Lloyd (Shepley et al., 1990) and the 'microstructure'⁸² method by Breen et al. (1994), but none has been able to show the evidence that a designer would prove the 'simulated' and 'scaled' varying nuances of fabric drape.

Fabric bending and drape are of great importance in developing 3D-PDS, and researches into fabric drape simulation are increasing. At present the main researchers are Govindaraj at the Philadelphia College, Ruff at the Rensselaer Polytechnic Institute (US), and McCartney and Hinds at the Queen's University (UK). However, this study uses a single fabric (i.e. medium weight calico) and one particular garment form to examine an existing 3D-PDS, in particular, the electronic pattern stability and inconsistency tolerances for garment use. With this specific approach, the related academic research will concentrate only on the pattern, in order to clarify and compare the specific problems in the pattern selection.

3D pattern design

3D electronic garment and pattern design is a developing field. Several related precursory works about garment pattern development came up with the concept of developing a 3D garment pattern design system.

⁷⁹ i.e. the visual look of the garment.

⁸⁰ i.e. the simulated garment drape can be incorporated into mechanical parameters in engineering (e.g. for pattern application).

⁸¹ This model is established for solving problems of stress, heat flow, etc. This technique is based mainly on dissecting the structure into simple elements, such as nodes, sides, and vertex. These simple elements can then be calculated using mathematical equations, the result of the calculation can also be displayed, e.g. the triangular meshes. (Shiple, D in Creasy, C and Craggs C, 1990).

⁸² This model simulates woven fabric by representing the crossing points of warp and weft yarns. This is done by more sophisticated processes, details can be seen in Breen et al., 1994

Douty (1968) pioneered the somatographic technique to help identify body variations in forms and shapes. It first related body construction to a garment pattern using silhouette photography, and later was used to determine body angles and curves (Shen and Huck, 1993). This showed some similarities to the later development of the 'converted 3D' (see section 3.2.3, p.3-38). This is via the captured 2D photographic image in conjunction with pre-established models (i.e. body model or garment stand) to estimate body measurements and shapes. This was regarded as part of the '2D pattern' development.

Hutchinson (1977) used a measuring apparatus, which provided the three-dimensional Cartesian co-ordinates for identifying body shape, to investigate the relationship between the body and pattern shape using the 'moulding'⁸³ technique. This approach may identify the body form in relation to the pattern shape, but the 'moulding' technique ignored the 'textiles' and 'garment ease' factors and was not applicable to the majority of the textile characteristics. Hutchinson (1977, p.74) proposed mathematical formulae to assess the forward angle of the shoulder and the shoulder depression using the measuring data. However, Efrat (1982) found that Hutchinson's method, apart from the angle and forward of the shoulder, appeared not to be completely satisfactory for all the body parts. The pattern shape was still the most important problem to be evaluated.

Efrat (1982) later developed the conic principle which intended to establish two-dimensional co-ordinates for the crucial pattern shaping points. Efrat defined the bodice as comprising 31 triangular planes (16 for the front and 15 for the back panels). The bust and blade were the two prominent points which were used to generate these triangular planes. In practice, it is very unlikely to be valid to construct a close fitting garment form using such numbers of darts or seams. Therefore, the problem was how many pattern panels would be needed in order to obtain reasonable patterns, i.e. both pattern shape stability and pattern accuracy which can be obtained for a 3D garment form and 2D patterns. Yet, the 'garment ease' was not taken into account.

⁸³ Hutchinson selected the material which was made of 'polyethylene foam sheeting' to mould the garment stand (Hutchinson, 1977, pp.123-136).

Later, Heisey et al. (1988) pioneered a theoretical framework for modelling the physical process of fitting a garment by drafting a three-dimensional pattern. They assumed that 'a projection that caused distortion that was acceptable or compatible with the end use' could be defined. Despite that, they also acknowledged that a sphere or any other dual-curved surface is non-applicable to a planar surface. This may be seen as the earliest theoretical development of a 3D pattern design for garment amongst published papers, but there was little evidence to prove it worked in practice.

Okabe et al. (1992) later developed what they regarded as 'the first 3D apparel CAD system in terms of the mechanical analysis of draping from 2D paper pattern to a 3D form, the development of a 3D surface to a 2D pattern, and the pre-processing which accepts arbitrary paper patterns for input'. However, CDI confirmed⁸⁴ that it launched its first 3D software onto market in 1987. The principles that Okabe et al. applied had many similarities to the Asahi's 3D system (pp.3-58 ~ 61), i.e. obtaining a 3D pattern through a pre-established 2D pattern. Nevertheless, they did not provide evidence to show the pattern accuracy and shape stability when using their system to flatten a 3D form.

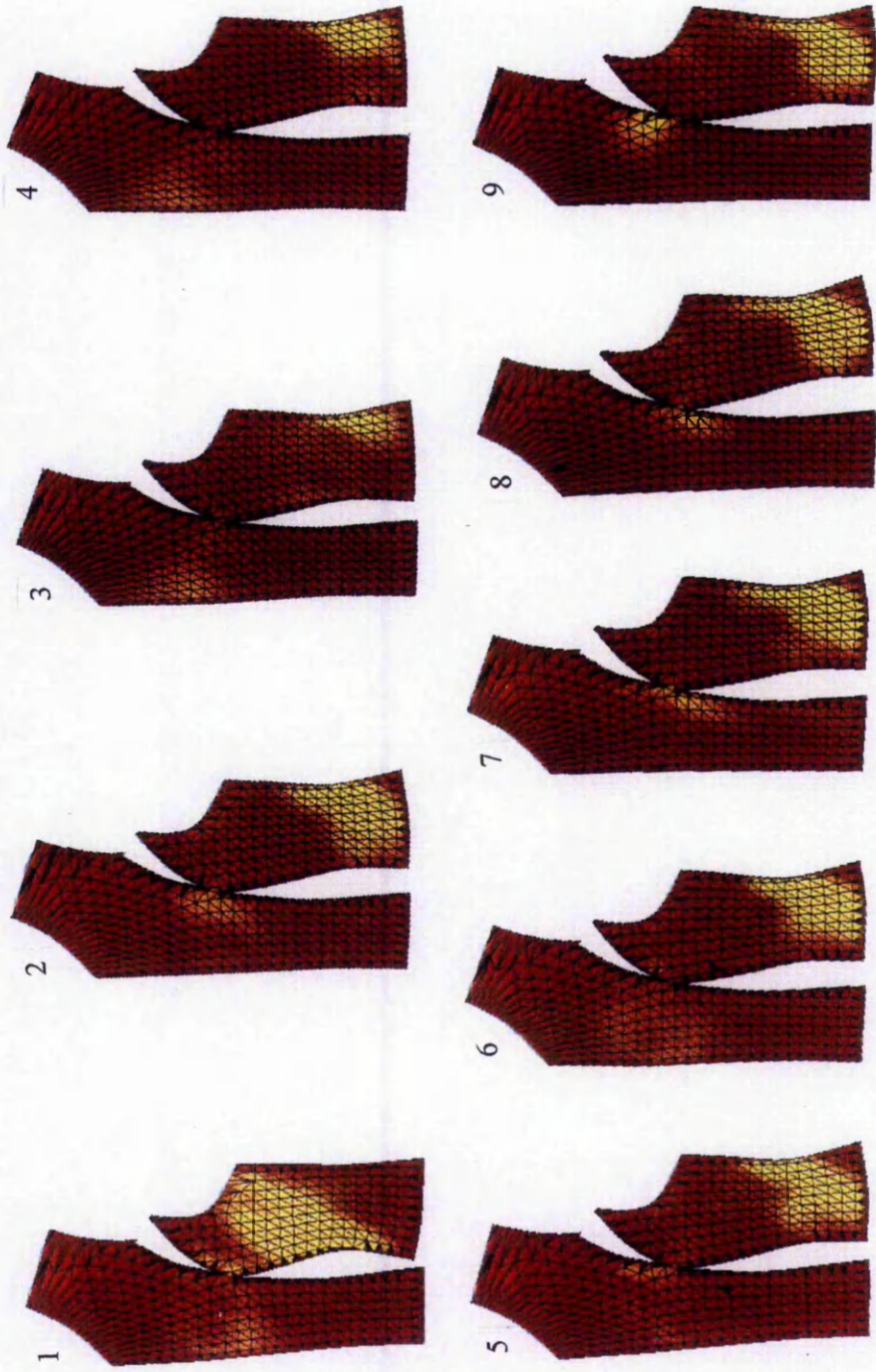
Hinds et al. (1992), based in Queen's University Belfast, have been developing their 3D-PDS since the mid 80's. Their current developments⁸⁵ are focused on improving the '3D to 2D' flattening and simulating '2D to 3D' drape. The first applies triangular meshes instead of stripes projection which was used in their precursory work, the second is using the approved 2D pattern shape to simulate garment drape directly on the garment stand. Although they also use strain analysis to show the electronically flattened pattern, no clear specification is made to identify the tension and compression which is caused within the pattern (Figure 3.27).

Importantly, they also realise that electronic flattening could cause pattern shape variations. Figure 3.27 shows a typical 2-dart FRONT bodice pattern for a close fitting

⁸⁴ By Lucinda Pant, marketing co-ordinator in the CDI, dated 11 Sept. 1997.

⁸⁵ A project, funded by the 'Engineering and Physical Sciences Research Council' (EPSRC), has been undertaken by Hinds and McCartney (Dept. of Mechanical Engineering, Queens University, Belfast) in collaboration with Mark's & Spencer, Coats Viyella, and the CDI Technologies Inc. (Direct contact with Hinds and McCartney, dated 8 May, 1998. Researcher Gong is involved in 2D to 3D draping and researcher Loo is dedicated in improving the accuracy of 3D to 2D flattening).

Figure 3.27 The pattern shape variations in the electronic pattern flattening



This figure (about 1 : 10) was courtesy from S. Loo, the Hinds and McCartney's research group, Queen's University Belfast, in the UK (dated 8 May 1998). The red and yellow indicate the 'stress and strain' in the pattern (at this time, they could not give information with regard to particular mathematical properties).

garment. 9 different pattern shape variations were caused when selecting different points from the 3D FRONT bodice pattern to flatten. Care must be taken where pattern shape variations corresponded with the changes of the 2 darts. Amongst these 9 patterns, the side bodice pattern areas appeared to be distorted more than the centre front pattern area. In the sample pattern 1 (see Figure 3.27), the side seam was almost a straight line which was inconsistent to the rest of the others; this distortion caused severe shapes for the 2 darts. The most contrasting changes in the front waist and armseye dart widths were Sample patterns 8 and 9; in pattern shapes are Sample patterns 1 and 8, particularly in the side bodice pattern areas.

It has to be realised that if pattern shape variations can be seen visually even when it is in a one-tenth scale, it is clear that the variations will be much more significant when it is in a full size pattern shape. This is investigated more fully in this study (see Chapter Five), but this problem still remains.

Other applications of 3D digital data and automated pattern drafting

The Hohenstein Institute for Clothing Physiology e.V. is currently working in collaboration with the 3D scanner supplier Tecmath (see section 3.2.3, p.3-33), CAD supplier Expert Systemtechnik, and clothing machinery supplier Pfaff for a project entitled 'Production 2000' (see "Production 2000"), supported by the Federal Ministry of Education, Science, Research and Technology, Germany. This project, primarily for men's outer wear, is aiming to 'develop and realize an integrated process chain for industrial production of clothing made to measure'.

Clemson Apparel Research⁸⁶, based in South Carolina, uses 3D scanned data to develop software, e.g. an expert system for size prediction, linking with existing pattern alteration software for made-to-measure uniform production and to the computer modelling of an individual body for custom pattern development. Expanding use of 3D digitising data shows its increasing importance for a future 3D virtual world.

⁸⁶ web page at '<http://hubcap.clemson.edu/~apparel/projects/3D.html>', pp. 1-3.

The Computer Clothing Research group, based at the Nottingham Trent University (UK), is developing the 'Virtuosi' system which is aimed mainly at developing a CAD package to help garment designers working 2D pattern shapes into 3D garment styles (Gray, 1998). This research group may provide a potential perspective for the future garment industry; however, from the basic block pattern illustrated, problems can be identified such as the inappropriate front pattern width, front armscye shape, and inconsistency at underarm area.

Clearly, advanced pattern technology is a widely researched feature for the future garment industry. This needs not only modern 3D technologies input, but garment pattern expertise input. Importantly, a mutual understanding between both disciplines is crucial and is an important aspect of this study.

3.6 Conclusion

Having investigated the 2D/3D CAD systems available, it has been found that 2D-PDS may provide some useful features in pattern development by means of manipulating digitised 2D blocks or patterns, but it is inefficient in interpreting design; some 3D CAD systems have been commercially available for decades, but there is little evidence to demonstrate to garment designers and pattern cutters that this 3D modern technology is practically useful for them. In particular, the issue of pattern distortion in a 3D CAD environment has not been made clear to the designers and cutters. Clearly, the success of 3D CAD software needs its user's approval rather than system marketing people or software developers' promotion. Therefore, experimental work to prove the feasibility of this modern technology is required.

Related academic research varies from garment pattern draping to linking digitising to made-to-measure garment production and other relevant academic research in 3D pattern design concentrates mainly on mathematical calculation or computerisation which has ignored manual cutting expertise. Having realised this, it is seen as crucial that a different approach to this modern 3D technology will need to take account of the knowledge of garment pattern cutting expertise. This would need the selection of one leading system for the experiments.

Very importantly, it is also noticed that no 3D system or research group seems to pay attention to the ease factor by which pattern discrepancies between 3D and 2D are often counteracted in the real world. This key issue has not been addressed fully by the 3D systems available, but it is one of the most crucial factors which determines the quality of a garment pattern and the garment fit. From researches into the related 3D technologies available and academic approaches, it is found that electronic pattern deficiencies, i.e. inconsistent pattern shapes, pattern edge measurements, and areas between 3D and 2D patterns, are the crucial issues to be evaluated. Only by understanding the problems as perceived by an expert pattern cutter can the 3D-2D flattening process be improved, or at least necessary improvements specified.

Amongst 3D systems available, the CDI-3D provides most of the best features for 3D garment design; however, whether the electronically flattened patterns are efficient for garment production use has to be judged by garment pattern expertise, so that tools may be developed to rectify the deficiencies which are caused in the pattern distortion. Based upon this consideration and the fundamental constraint of mathematical computation, it is seen that, in order to demonstrate when electronic distortion is caused, manual pattern cutting expertise may be a core means to be used as pattern approval is offered mainly by pattern cutters. In order to learn this adjustment skill of manual pattern cutting expertise, conditions in the virtual world need to be like conditions in the real world. Comparative results may assist, later, in obtaining good quality electronic patterns.

The CDI-3D software used in this study is version 5.2, with 128 MB memory, and runs under Silicon Graphics ('Indigo 2 Extreme') workstation using a 200 MHz processor and a Silicon Graphics monitor together with a keyboard (see Figure 4.25, p.4-55).

4 INVESTIGATION PROCESS

4.1 Introduction

In general, a 3D garment pattern cannot possibly have both identical pattern 'area and periphery' together when flattened to a 2D garment pattern¹ because the strain and stress within a 2D pattern surface is not the same as they are in the 3D (see section 3.4.3, pp.3-68 ~ 70). In turn, pattern inaccuracy as far as garment construction is concerned is bound to exist in mathematical computation alone. In order to examine and improve this limitation of the modern 3D technologies available for use in the garment industry, devising a basic *garment form* together with valid garment patterns in the virtual world is seen as crucial for a future 3D-PDS which this study will present.

In practice, in 3D manual pattern making, pattern inconsistency is usually eliminated by the combination of garment ease, fabric bending ability and iterative pattern modifications. Clearly, the subjective human factor inevitably exists owing to the lack of a concrete 3D garment form (i.e. unstabilised garment ease). This results in the individual use of the term garment fit in the real world, but it is this subjective factor which will judge garment pattern consistency. Difficulties can occur about how to assess this subjective factor, in an objective way, in order to conduct objectively an identical process for practical use in a future 3D-PDS.

It is therefore acknowledged that a 3D garment form needs to be established consistently in the real and virtual worlds so that electronic pattern inconsistency can be analysed in comparison with manually toiled pattern stability and consistency. This is an essential requirement of the garment pattern making user environment for a future 3D-PDS. Importantly, manual 3D garment pattern making expertise may have insight for the improvement of pattern inconsistency in the virtual world.

¹ Note that a simple form, e.g. a cone, could have a consistent pattern between 3D and 2D.

Prior to applying the manual method, it was seen that the subjective manual pattern cutting variables in the real world had to be reduced to the minimum possible. This meant that the garment ease factor ought to be under complete control.

4.1.1 The Structure of the Hypothesis

The hypothesis of this study claimed that 'If all variables are controlled in a comparatively consistent condition (between the real and virtual worlds), 3D electronically flattened patterns ought to show an equivalent quality fit in the pattern edge measurements and shapes when compared to manually toiled patterns'. The processes by which to clarify this electronic pattern flattening and distortion can lead into viable applications for exploring the limitations of modern 3D-PDS.

It was decided that, to test the hypothesis, certain conditions should be met. First, it must be possible to create and control consistently a garment form to be identical between the *real* and *virtual* worlds, so that pattern comparison can be made. Second, the exact meaning of the 'electronic pattern deficiency' should include not only inconsistent measurements of the pattern periphery and pattern area between 3D and 2D patterns, but also the stability and repeatability of pattern shape. Third, the electronic pattern distortion can be shown when compared with the manually toiled pattern. Finally, an electronic pattern is deemed to have been obtained only when it conforms to some cutting principles, based upon the knowledge gained from the comparative experiments.

4.1.2 The Development of the Methodology

It was hence decided that this study could investigate into the electronic flattening process through a comparison of a controlled 3D manually constructed garment pattern with an identical 3D electronically constructed pattern.

Prior to any discussion of the method established, a clear definition of three basic terms used in this study needed to be defined (Figure 4.1). The process of controlling this investigation required that five problems had to be addressed.

First, a viable sample garment form (see Figure 4.1) had to be developed for use in controlling 3D manual pattern cutting in the real world.

Second, the developed sample garment form also needed to be viable for controlled 3D electronic pattern cutting in the virtual world. This meant that, in order to allow a valid comparison to be made between the manually and electronically flattened patterns, a method of creating (i.e. by data input) a virtual sample garment form that was identical to the one in the real world had to be established.

Third, the process of controlling the specific variables in 3D manual pattern cutting needed to be conducted consistently in order to provide a relatively objective foundation pattern (see Figure 4.1) that could enable controlled pattern comparisons to be made.

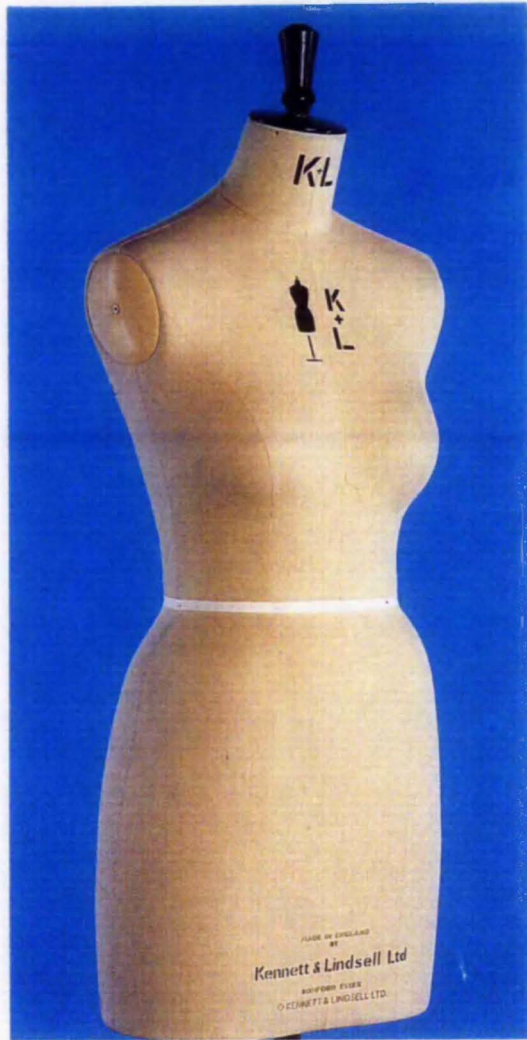
Fourth, in order to compare manual and CDI-3D flattened foundation patterns, a means of working with both patterns in the virtual world was needed. A linkage between the CDI-3D system and the AccuMark 2D system was required (see section 4.6).

Finally, this research argued that if this method could produce a controlled 3D electronically flattened pattern that could be compared with the controlled 3D manually toiled pattern, then it would seem that this could provide a secure base for future 3D electronic experiments of flattening more complex garment patterns in the virtual world.

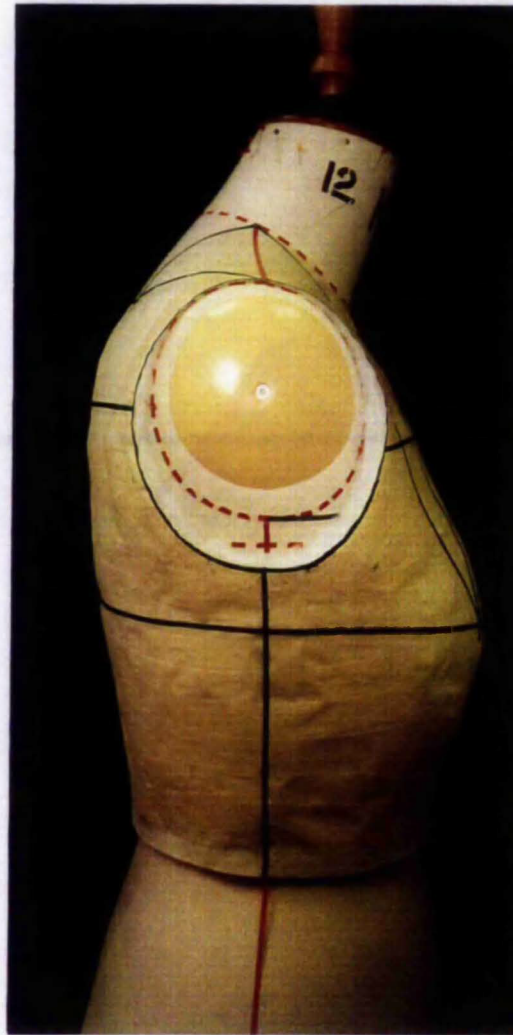
4.1.3 The Significance of Preliminary Research

Investigations which related to the garment patterns were described as follows. In Chapter One, this study presented an important argument in which 'ease' was the key factor which made all the inconsistent pattern change unclear (see section 1.1, p.1-3).

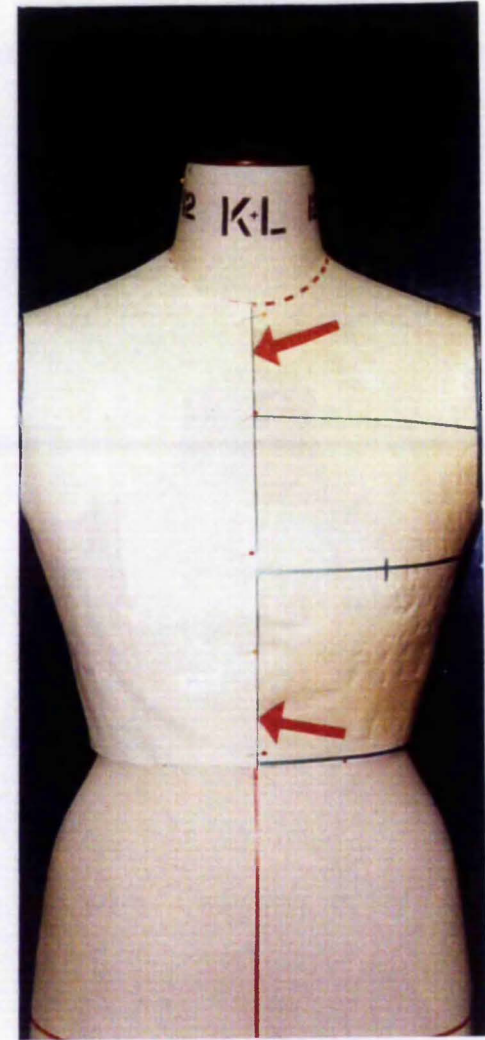
Figure 4.1 The illustration of the three basic terms used in this study



Garment stand



Sample garment form



Foundation pattern

This meant that manually toiled 2D patterns may be also different from 3D patterns but both became compromised consistently because of the garment ease, fabric bending, and the final modifications to the adjacent patterns.

In Chapter Two, 2D manual block drafting for a close fitting bodice often used two darts to shape the bust, i.e. one on the shoulder and the other on the waist (see section 2.4.2.2, Figure 2.8). This technique has been adapted skilfully by each individual pattern making expert with his/her empirical knowledge and experience; however, it is necessary to inquire if it would also be applicable to a 'contact-fit' (i.e. skin-off) pattern cutting. The clarification of this argument will help to profile a better 3D electronic and manual pattern construction for the later comparing and contrasting of patterns.

Fundamental elements for 2D and 3D manual block construction were divided into 'body, size, block, and fit', (see sections 2.2~2.5) and the use of the term fit was also clarified specifically (see section 2.5). This clarification will help to specify the bases for comparison with 3D electronic pattern (see section 5.4).

In Chapter Three, it was shown the fact that 3D electronic pattern deficiency was bound to exist for garment use (see section 3.4.3), and it was seen as vital to investigate whether this deficiency could be analysed and predicted.

It was acknowledged that 3D-PDS was fundamentally a process of fitting a form surface (i.e. 'contact-fit', see sections 3.4.2 and 5.1, Figure 5.1), which meant that, in practice, the thickness of the form surface should have been considered. However, this factor was conditionally ignored because the garment form surface used in this study was a pre-defined calico which did not significantly affect the flattened pattern. The CDI-3D system was selected for later building the virtual garment form because it had a pattern flattening function (see section 3.4.2). The LASS was selected for later inputting a garment stand and the sample garment form into the CDI-3D (see sections 3.2.4 and 4.3). It was also realised that the CDI-3D needed to be linked with the Gerber AccuMark 2D-PDS for comparing the manually and electronically flattened patterns.

The pattern flattening program in the CDI-3D system was developed in association with mechanical strain and stress analysis. The problem occurs where, using mathematical computation alone, either pattern periphery or pattern area is bound to be different between 3D and 2D after releasing the stress and strain from flattening as far as possible. However, it is still worth noting that there must be some parameters which could make an electronically flattened pattern close to the manually flattened pattern solution. The parameters which resulted in this better solution could finally be used for the practical experiments of the foundation patterns.

Finally, it was essential to compare and contrast pattern change between 3D and 2D in practice both for electronically and manually flattened patterns. It would be an important development if the pattern change in the electronic system could be related to the change in the manually flattened pattern. The comparative results will become the criteria to evaluate the electronic pattern deficiency for garment use in a future 3D-PDS.

4.1.4 Identifying and Stabilising the Related Variables

The establishment of a 3D garment form in the real world involves the control of many related variables, i.e. the different types of industrial garment stands, the required garment eases in relation to the individual use of the term fit, the different requirements of the suppression, different fabric draping quality, and pattern changes in accordance with fabric and design factors. These variables would need to be reduced and stabilised for later establishing, in theory, an identical 3D sample garment form in the virtual world.

A 3D sample garment form was required, in the context of close fitting garments, to include not just a stand, but also the basic ease for body movement using 3D and 2D garment pattern making expertise (see sections 2.4.2.2 and 2.5.4). Having acknowledged the context of this study, three main variables were specifically focused on: the garment stand, the sample garment form, and the fabric when the foundation patterns were developed. In this study, the garment stand factor was seen as a part of the garment form factor in the later experiments.

These three related variables were modified from the four fundamental elements for manual garment pattern making, i.e. the body, size, block, and fit (see sections 2.2~5). The body was replaced by the selected garment stand in order to stabilise the live factor; the size grading was ignored at this stage in order to focus specifically on the pattern construction; the block and fit were interpreted by the sample garment form and foundation pattern. Finally, the fabric² factor was taken into account in order to create the foundation pattern and to undertake the later practical experiments.

For the garment stand variable, many different types of industrial garment stands, produced by the Kennett & Lindsell Ltd.³, were assessed in conjunction with contemporary garment pattern cutting experts' use of size charts (see section 2.3). The 'size 12' garment stand in W.E.D. range was finally selected because its main control measurements (i.e. bust, waist, hip, and nape to waist) were more up to date and the human body form and shape were more realistic. However, the waist girth was reduced 2 cm from the original 70 cm to make later pattern comparison easier to be identified.

With the sample garment form and pattern variables, it was found that a close fitting sample garment form in a solid surface was crucial in order to obtain consistent manual 'foundation' patterns. The solid surface was to keep the garment form in consistent construction so that the pattern construction could be defined more objectively; the 'foundation' pattern was to focus on the 'contact-fit' garment pattern in non-stretch fabric for useful application in the future.

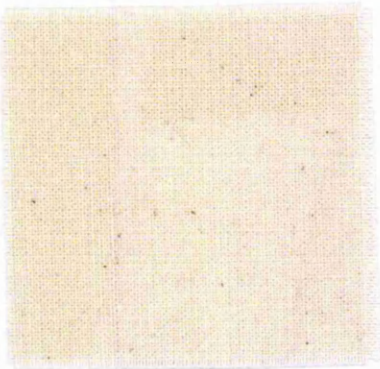
With the fabric variable, eight calico samples produced by Whaleys⁴ were presented to nine garment pattern cutting practitioners who were questioned about their criteria for selecting a toile fabric to make a foundation pattern (see Appendix 1). The medium calico was found to be the most appropriate for this project because of its stable construction, particularly in its low formability and its bending and shear rigidity (Figure 4.2).

² The fabric factor was not involved into the process of manipulating the 3D foundation garment form in the real world, but it was used in manually toiling 3D patterns to 2D patterns.

³ The most famous industrial or individual garment stand manufacturer in the UK, based in Essex (Tel. 01708-749 732; Fax: 01708 - 733 328)

⁴ A fabric manufacturer based in Bradford, West Yorkshire (UK).

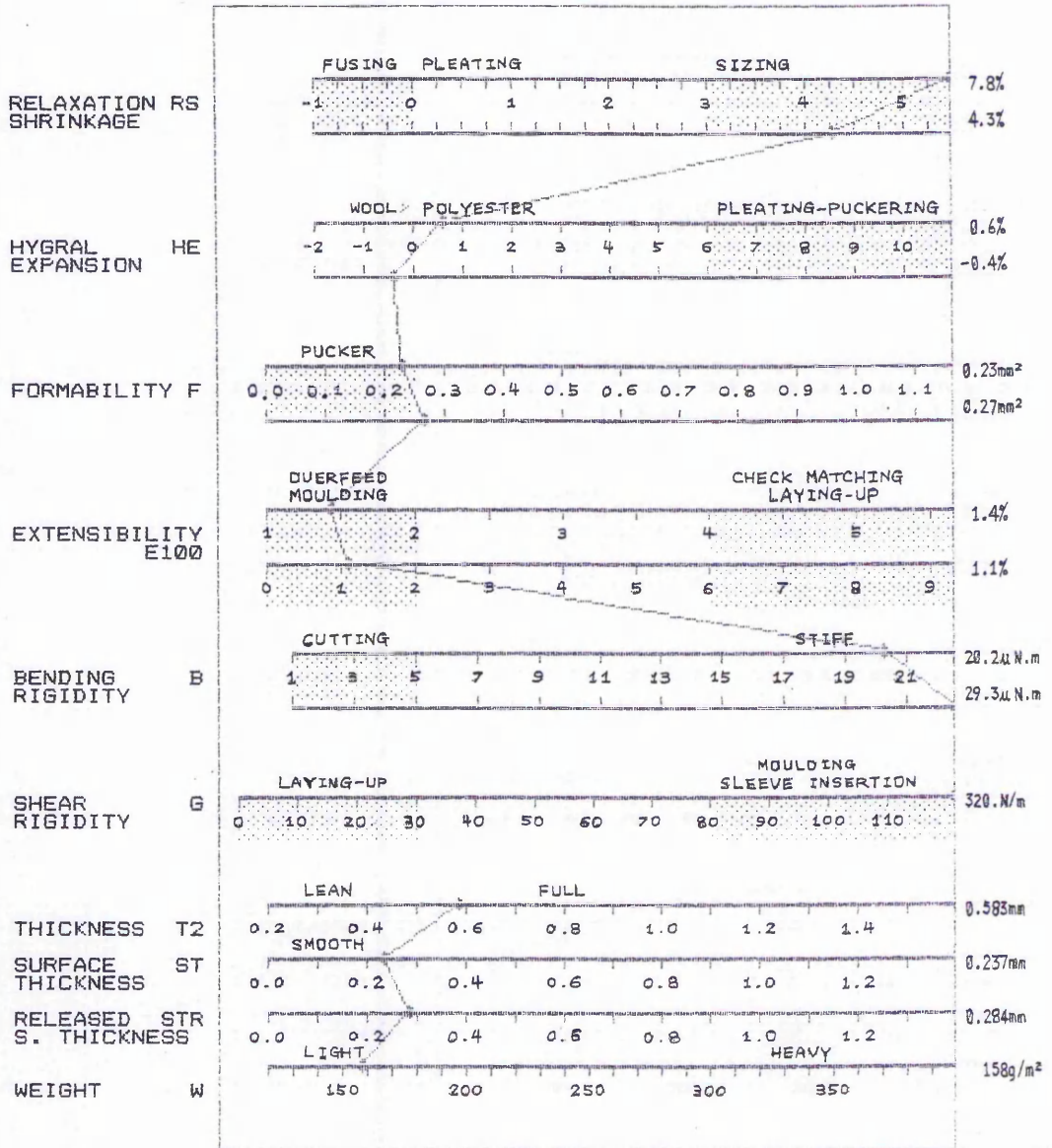
Figure 4.2 The FAST testing result of the calico sample used in this study



FAST CONTROL CHART FOR TAILORABILITY

FAB. ID :
 END USE :
 REMARK :

SOURCE :
 DATE :



4.2 Creating a Sample Garment Form in the Real World

The sample garment form based on the Kenneth & Lindsell's garment stand was made in solid type (see Figure 4.1), it required that three elements had to be addressed, i.e. the purposes, requirements, and processes. The aim was to create a standard garment shape that included ease allowances.

4.2.1 Purpose

Making the sample garment form in a 'solid' type was to make it possible in theory for the sample garment form in the real world to be duplicated in the virtual world and to reduce the subjective human factor to the minimum possible. This approach was seen as the only method which could examine practically the electronic pattern deficiency for garment use in the 3D-PDS.

4.2.2 Requirements

The 3D solid sample garment form in the real world was produced through padding ease on the selected garment stand. The ease distribution was referenced with the selected garment cutting experts' use of the ease in their basic block construction (see section 2.5.4, Figure 2.17) and the smoothness of the final garment form in practice. In order to pad the selected garment stand with different eases distributed over the different areas on the garment stand, three basic requirements of padding needed to be specified. They were: first, the selected padding material needed to be as soft as skin and stable enough to support the form consistently; second, important control landmarks were required to be identified in order, later, to control patterns more consistently; finally, the important landmarks and measurements needed to be identified in accordance with the net garment stand and the sample garment form. Marking tapes were required to identify control landmarks and measurements.

4.2.3 Processes

Identifying landmarks and measurements on the selected garment stand

The necessary landmarks and measurements of the garment stand required to be identified before padding eases for the sample garment form. This process was needed for later specifying the quantity of the eases added-on.

These landmarks and measurements were identified using 0.3 cm wide marking tapes. The placement of each landmark on the garment stand was determined by the researcher's visual judgement together with reference to the practical uses by contemporary garment pattern experts (see sections 2.4~2.5). Details for the numbers and positions of the landmarks and measurements were listed in Figures 4.5~7.

Padding with different eases on the garment stand

The padding material was required to be as soft as skin and stable enough to keep the sample garment form consistent. Particularly, the solid type of the sample garment form needed to take the factor of frequent uses into account because the toiling process would, later, take place for 'forty times four' patterns, i.e. eighty toile and eighty paper patterns.

The selected padding material was a 'wadding'⁵ of white polyester. The inner layers of the wadding material were ironed in order to produce a strong base for the sample garment form. The padding process was divided into three sections.

First, padding with an ease of 7-8 cm evenly surrounding at the bust girth and an ease of 4-5 cm at the waist girth⁶. The ease at the waist was more generous⁷ for its practical

⁵ The wadding material was purchased at Jessops in Nottingham (UK), the John Lewis partnership. It was 96 cm wide and 2.5 ounce per meter. It cost 1.10 pounds per meter in March 1998.

⁶ The determination of the ease was in reference to the comparison of the six selected basic block constructions (see section 2.5.4).

⁷ This was in comparison with the average of the six selected basic blocks (see section 2.5.4).

application in adapting other garment patterns. Second, in this study, the armscye girth was formed spontaneously after constructing the primary control measurements (pp.4-13 ~ 18). Finally, the remaining eases were spread smoothly in accordance with the main control measurements. Masking tape was used to keep the ease at the right area and to support and stabilise the outer surface of the foundation garment form, so that the softness of the wadding material could be kept as the garment form was stabilised.

There was no need to pad an ease above the shoulder girth because of gravity, also the ease-padded sample garment form would not remain as a naturally 'relaxed' garment form below the shoulder area because the padded ease was of solid type, in turn this meant that the 'fabric drape' factor was not involved. Therefore, the sample garment form was remained as not overblown above the bust level (see Figure 4.1), but as minor 'inflated' beneath the bust level because the ease was padded in a solid type.

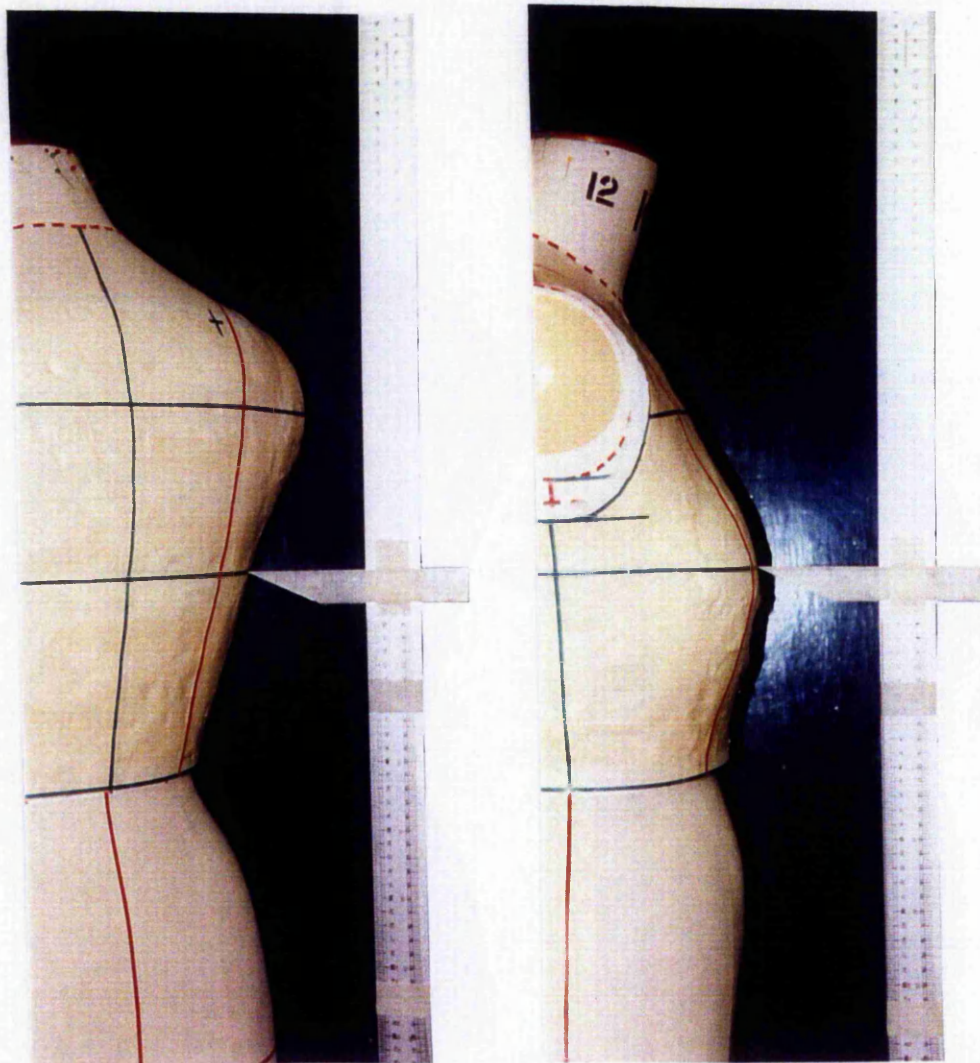
Keeping the sample garment form in consistent horizontal and vertical

Primarily, the sample garment form was placed on a flat and stable working table, the two horizontal and one vertical control measurements⁸ of the sample garment form required to be consistent to each other. This consistent relationship had to be established with regard to the measuring place and the distance to the working table. If the two horizontal control measurements on the sample garment form were controlled in parallel with the working table, then the vertical measurement could be constructed relatively.

A long square ruler was joined together with a sharpened small ruler in order to probe more consistently the required horizontal points contained in the two horizontal control measurements on the sample garment form (Figure 4.3). Primarily, the bust and blade points had to be identified so that the joined rulers could be adjusted to the equivalent height from the working table. The horizontal control measurements were taken by rotating the garment form and marking the points on the equivalent height position.

⁸ i.e. the measurements of the bust girth, waist girth, and nape to waist on the sample garment form. The same process was also applied to the garment stand, but an extra measurement, the hip girth needed to be added.

Figure 4.3 A square ruler joined with a sharpened ruler in order to probe more consistently the required horizontal points



The measurement of nape to waist was taken by fixing vertically a 0.95 cm wide tape, with a weight at the end, on the nape point (Figure 4.4). The centre front was also specified using the same method.

Specifying the primary control landmarks and measurements

The control landmarks and measurements for the sample garment form were identified as two main strands: the primary and the secondary controls. The primary control referred to the landmarks and measurements which would relatively result in a '3D skeleton pattern', i.e. a 3D pattern which wrapped the upper bodice torso and identified the basic proportion of the major bodice parts. These were centre back, across back, side bodice width, across front bust, and centre front (see Figure 4.5-4.6).

It was important to realise that these primary control landmarks and measurements were established on the sample garment form. These requirements were needed later to control the identical sample garment form in the 3D virtual world. In turn, the numbers of the control landmarks and measurements required for making up an identical virtual 3D sample garment form in this process would be an equivalent guide for making a 3D virtual garment form in a future 3D-PDS.

Specifying the secondary control landmarks and measurements

The secondary control referred to the control landmarks and measurements which were used to take off the bodice suppression, i.e. to shape the upper bodice torso at the waist and the shoulder areas. This included the front and back shoulder widths, across front, bust girth, and waist girth (see Figure 4.5-4.7).

In the context of a close fitting garment form, the distribution and the placement of the bodice suppression would determine whether the real garment would hang on the bodice properly. However, this factor was controlled temporarily by the researcher's visual

Figure 4.4 The method of marking the 'nape to waist' measurement

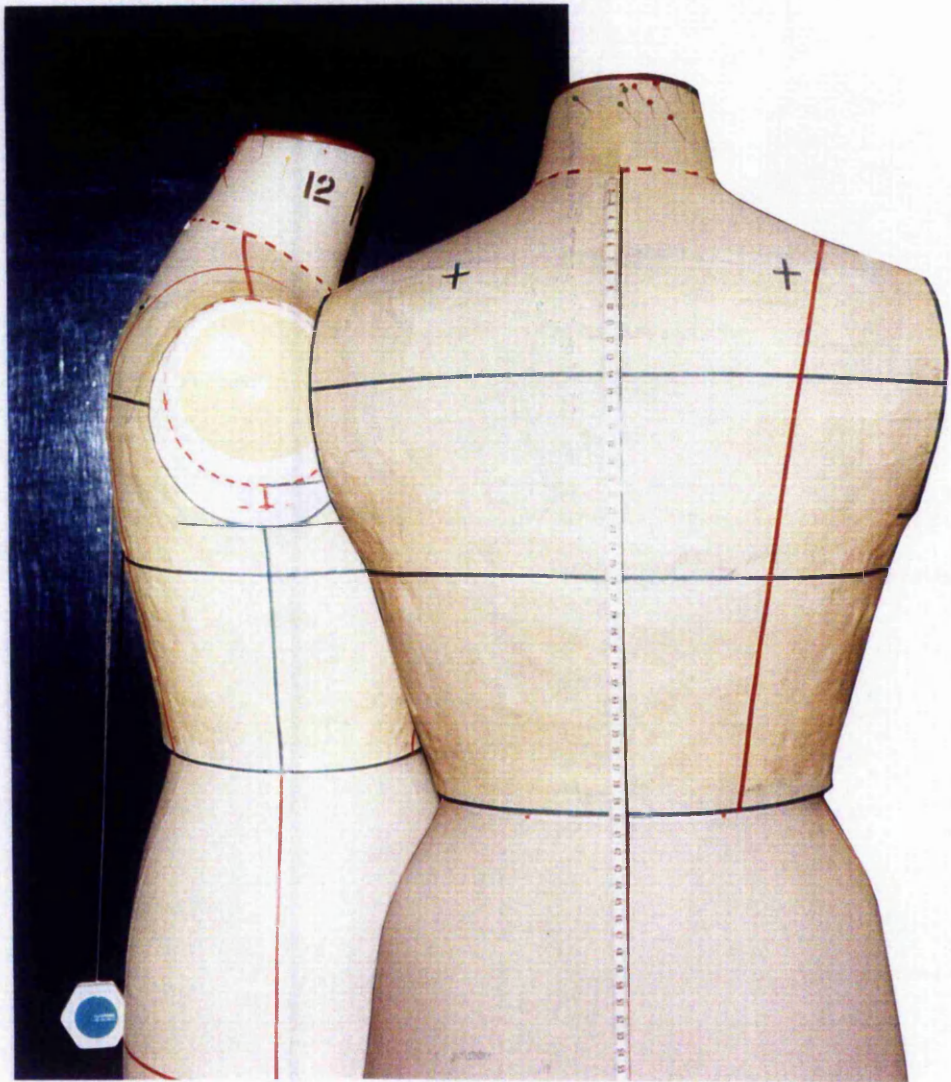


Figure 4.5 The list of the control measurement¹ specifications of the sample garment form used in this study

Primary control measurements :	Secondary control measurements :
Centre back	Back shoulder width ² Shoulder length
Across back	Front shoulder width ³ Underarm ⁴ to waist
Armseye width	Back bust girth Mid-shoulder to back waist ⁵
Centre front	Front bust girth Mid-shoulder to front waist
Across front bust width ⁶	Back waist girth Across front
	Front waist girth

¹ The width and girth measurements in this figure were referred to half of the actual measurements, except the armscye width.

² This measurement was taken from left shoulder point across the centre back to the right shoulder point.

³ This measurement was taken from right shoulder point across the neck point of the centre front to the left shoulder point.

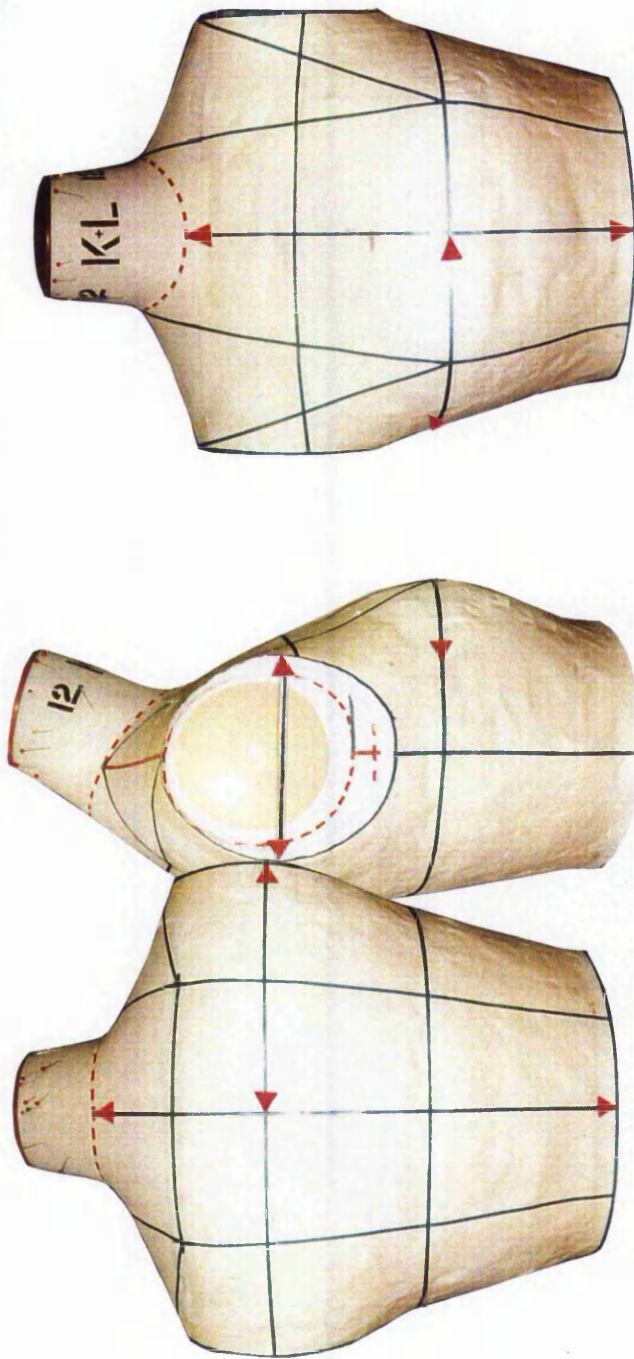
⁴ The underarm position was considered as the armscye depth of the sample garment form.

⁵ This measurement was taken from mid-shoulder point across the greatest convex area (i.e. the blade area) to the back waist.

⁶ This measurement was taken horizontally from the centre front across the bust point to the intersecting point vertically down from the across front width.

Figure 4.6 The primary control landmarks and measurements of the sample garment form, i.e. the '3D skeleton pattern'

Unit : centimetre



Centre back* : 40.70 [40.35]¹

Armscye width² : 13.70 [11.40]
(Garment form's)

Centre front* : 35.70 [34.5 / 35.3]³

Across back : 19.6 [19.50]

Across front bust width⁴ : 17.65 [16.35]

¹ The figures in brackets are the *net* measurements of the garment stand. The measurements listed above are 'half' measurements, except the measurements with an asterisk in the end.

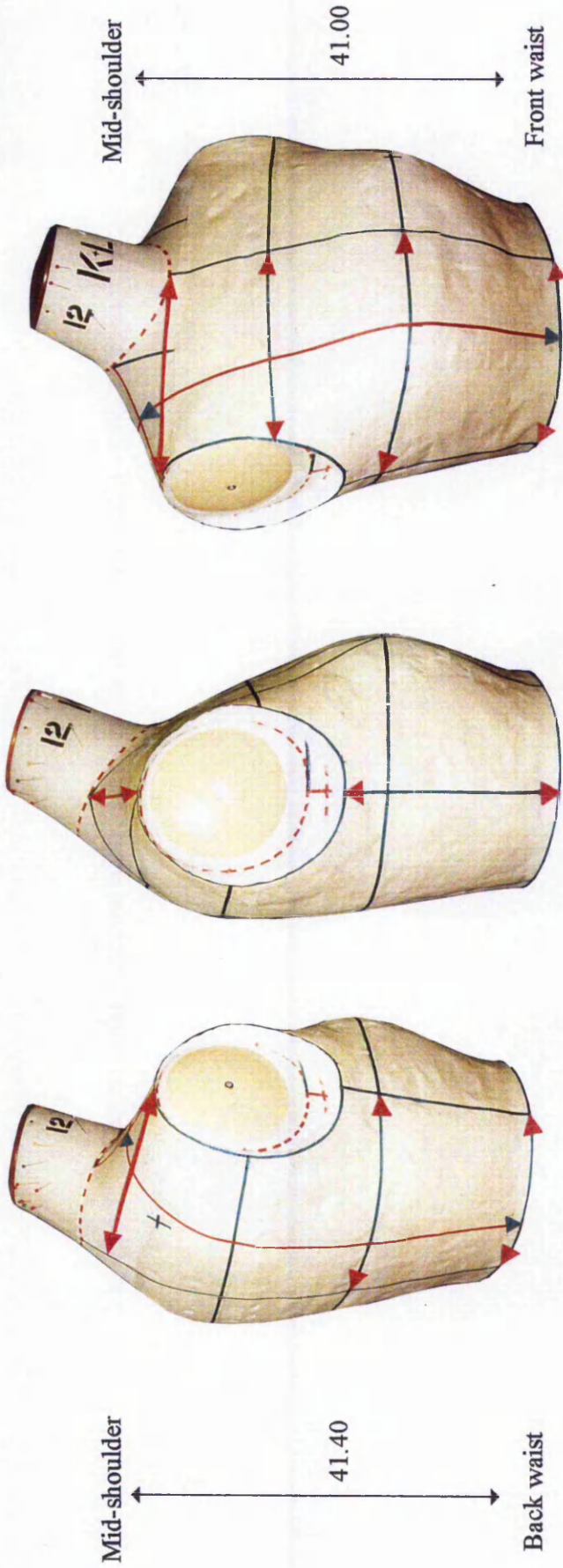
² This measurement is taken using the front and back armpit points vertically intersecting to the armscye depth level of the garment form.

³ The two measurements in brackets: the first was measured from the concave groove between bust points, the second was measured from the same level as bust points.

⁴ This measurement is taken from the visual 'across front width', but vertically locating at the bust line in order to obtain the major pattern width of the front garment form.

Figure 4.7 The secondary control landmarks and measurements of the sample garment form

Unit : centimetre



Back shoulder width : 19.80 [19.80]
 Back bust girth : 22.60 [20.50]
 Back waist girth : 17.70 [16.35]

Shoulder length* : 12.55 [12.55]
 Underarm to waist* : 18.55 [21]

Front shoulder width : 18.55 [18.55]
 Front bust girth : 25.35 [23.70]
 Front waist girth : 18.65 [17.65]
 Across front : 17.65 [16.35]

Note: All measurements listed above are 'half' measurements, except the two measurements with an asterisk in the end. The two measurements in red lines, i.e. mid-shoulder point to the front and back waist, are the two convex control measurements. The figures in brackets are the measurements for the net garment stand.

judgement and empirical experience. No further debate was made because this study concentrated specifically on controlling an identical sample garment form both in the real and virtual worlds. Comparatively, the correctness of the 'natural' garment form would be less important to argue because this factor had to be discussed in conjunction with the fabric factor. It should be emphasised again that the main intention of this study was to clarify the electronic pattern deficiency and to further enable the electronic pattern deficiency to be related to the manually flattened patterns in the real world, so that some insight into how to judge electronic pattern deficiency may be gained.

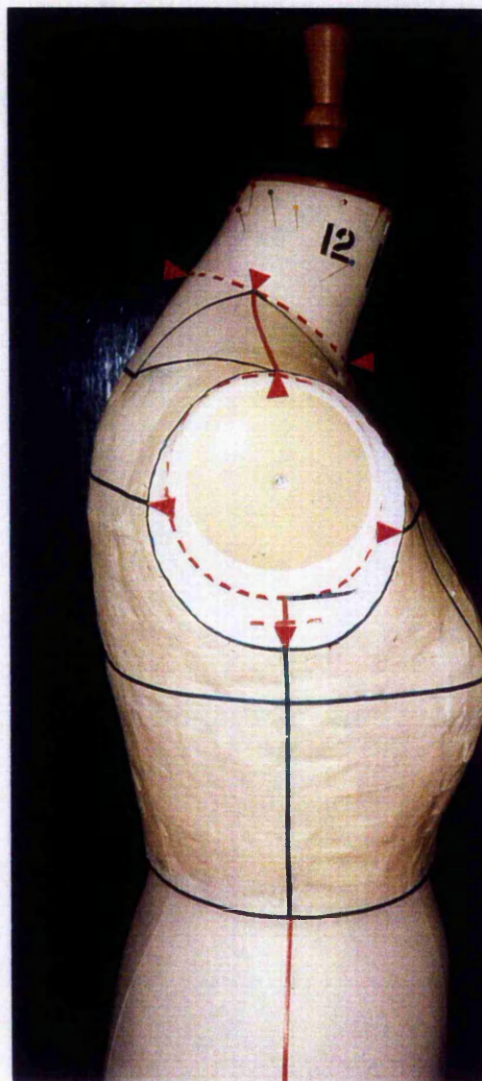
Shaping neck and armseye bases for the sample garment form

Having defined the primary and secondary control measurements, the boundary points were respectively the back, side, and front neck points for the neck base; the shoulder, back, under, and front armpit points (see Figure 4.8).

Size, measurements, and fit specifications of the final sample garment form

Having completed the above processes, it was necessary to specify clearly the final measurements and fit specifications between the net garment stand (of Size 12) and the padded sample garment form. This information was used in the manual toiling process to evaluate the accuracy of the toiled patterns. Importantly, the 'discrepancy tolerance' between the 3D and 2D manual pattern measurements could be identified later (see section 4.5.6.2, Figure 4.24).

Figure 4.8 Shaping the neck and armhole bases for the sample garment form



4.3 Controlling the Sample Garment Form in the CDI-3D System

4.3.1 Purpose

The method used for control of modelling the created sample garment form in the CDI-3D system was to devise a process by which to establish a comparative environment between the real and the CDI-3D virtual worlds, so as to investigate the electronic pattern deficiency for garment use.

4.3.2 Processes

The processes of establishing an identical sample garment form in the CDI-3D system was by digitising the sample garment form constructed in the real world. This adaptation was divided into two main sections: first, inputting the garment stand and the sample garment form data which were collected using a 3D digitising technique; second, generating⁹ and controlling the virtual garment stand and sample garment form in the CDI-3D system.

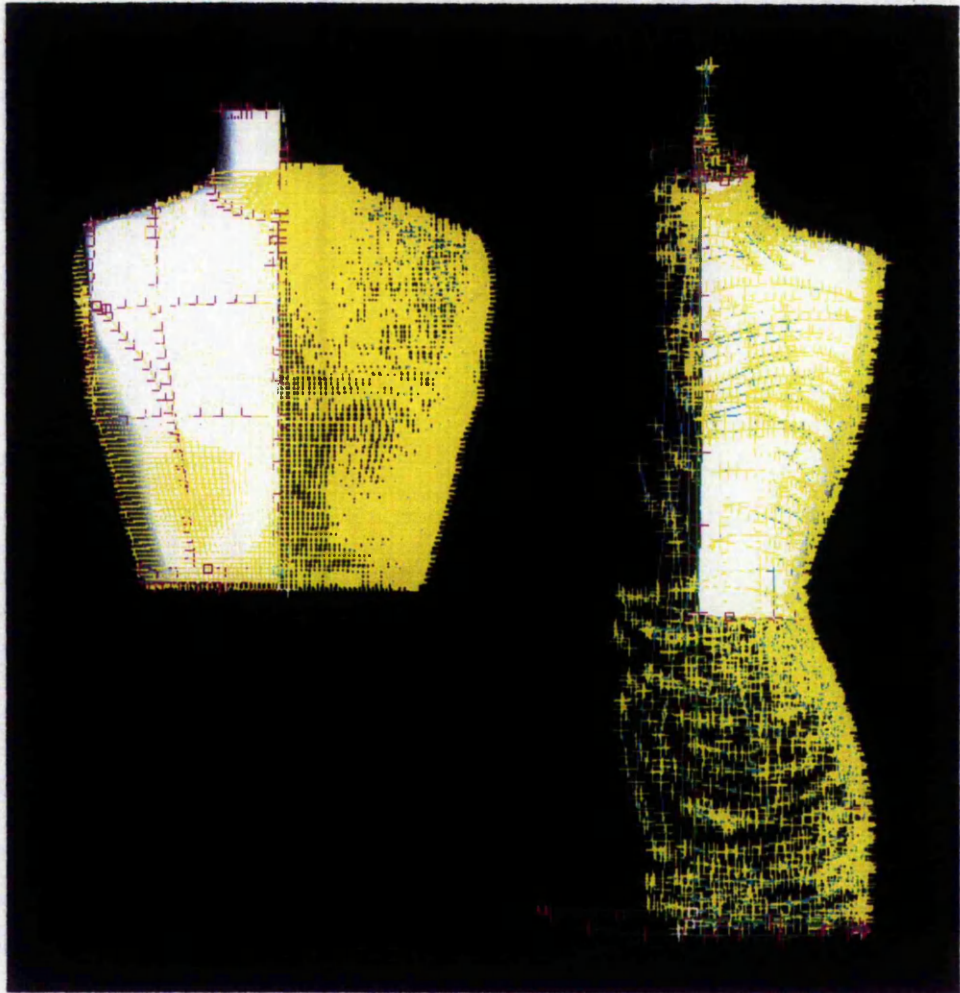
There are numbers of contact and non-contact 3D digitising techniques (see sections 3.2.3.1~2). The LASS was chosen to collect the sample garment form data as its data were compatible for use in the CDI-3D system (see section 4.3.2.2). Time¹⁰, economic cost, and the geographical convenience were the other factors considered.

Prior to using the LASS, there were two points to be addressed. First, this study collected the raw data of the sample garment form because they had original information regarding it. Second, the LASS required the scanned subject to be rotated while scanning, but this limitation did not constrain its use for this study as the stabilised sample garment form did not have the problem of live body movement.

⁹ i.e. to make the input 3D data visualised as a concrete 3D garment stand and garment form, so that the accuracy of the electronic garment stand and garment form could be proved for clothing applications.

¹⁰ It collected data faster than any of the contact 3D digitisers.

Figure 4.9 The contact and non-contact digitised data which were demonstrated using 'Wireframes' and 'Surfaces - Cloud' in the CDI-3D system



The sample garment form in non-contact digitised data which was used for this study.

The sample garment form in contact digitised data. Contact digitised data also could be obtained in an even data distribution by digitising on only pre-marked points. These data were provided by CDI (UK).

4.3.2.1 Digitising the sample garment form using the LASS

Although the garment form was manipulated only for the upper bodice torso (i.e. neck to waist), the full bodice at 91 cm in vertical length was scanned for use in the future. The total numbers of the cross sections regarding this input sample garment form were 182 slices at 0.5 cm intervals, each cross section contained 150 data points. Therefore, the total data were approximately 27,000 data points. The process of digitising this amount of 3D data took 2 minutes 38 seconds. It took 6 minutes 10 seconds altogether to complete the whole data collection¹¹. For specific use in this study, only the data points for the upper bodice torso to the waist would be needed. In turn, there were approximately 14,000 active data points for the sample garment form.

4.3.2.2 Inputting and checking the converted LASS data in the CDI-3D system

In order to make the LASS 3D data usable in the CDI-3D system, a process for converting the LASS data to the CDI's data format was needed to be made. This process has been developed by the HUMAG research team¹² as part of the project which was sponsored by ACME (see section 3.2.4, p.3-43), and major foundation wear companies in the UK, e.g. Marks & Spencer plc. and Courtaulds Lingerie.

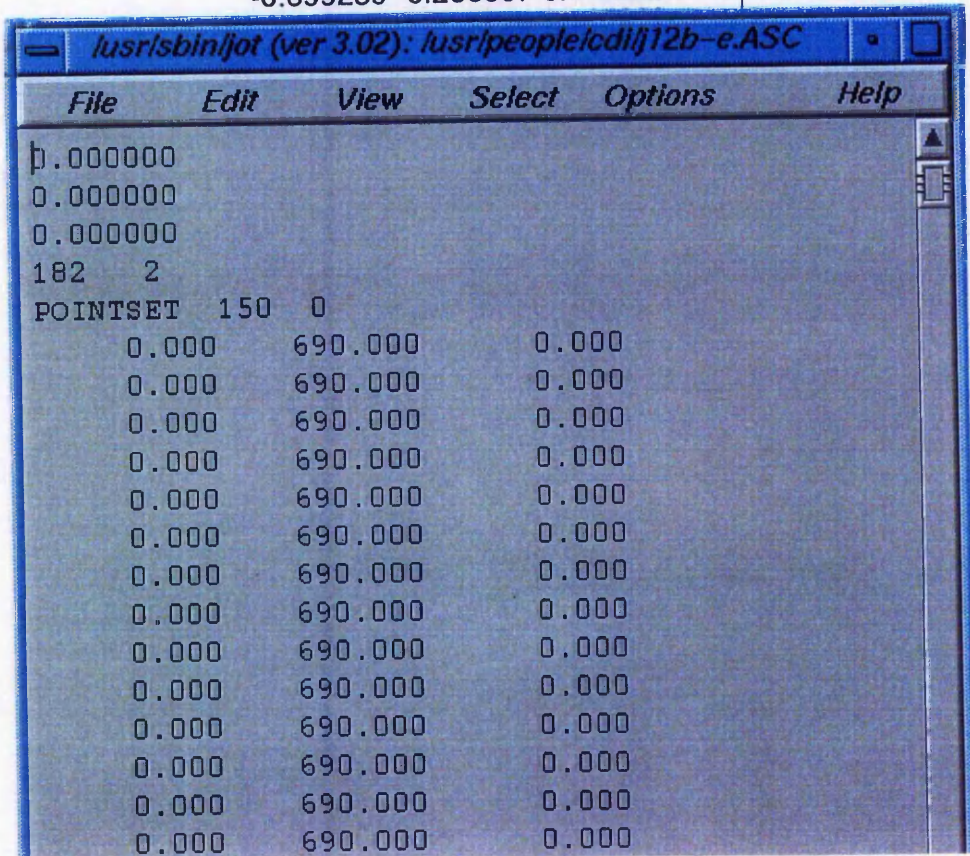
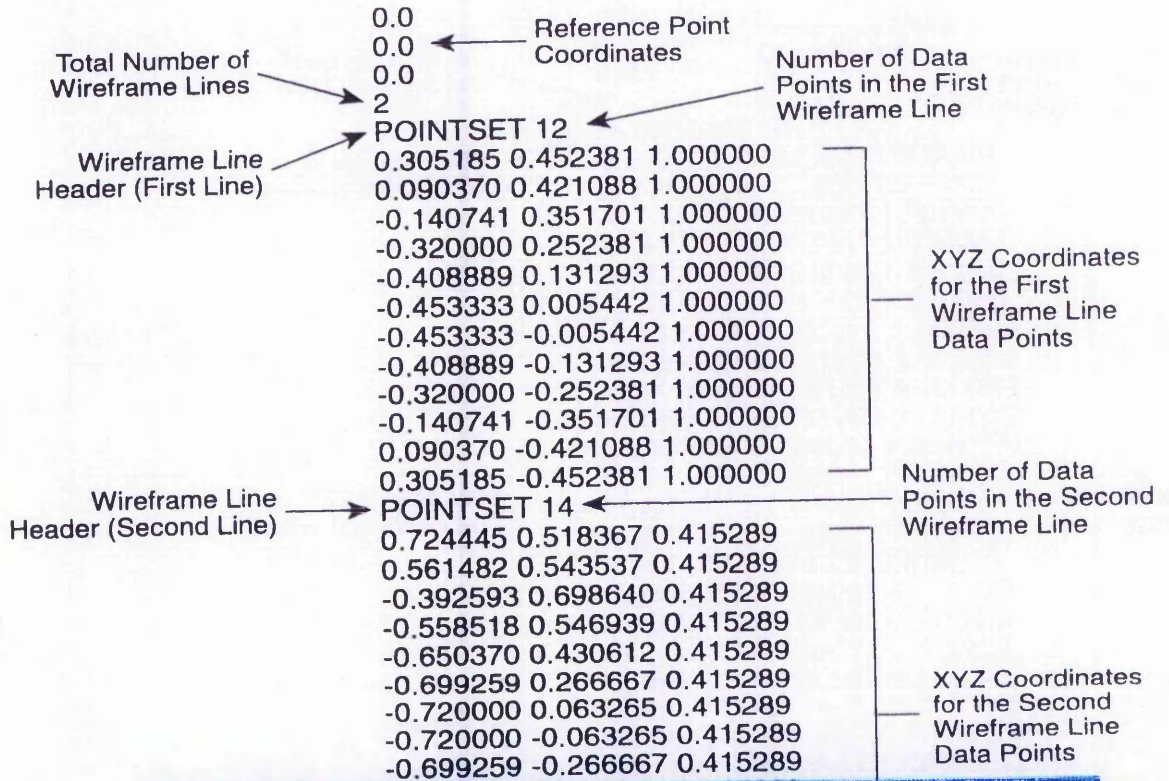
An ASCII file format is employed by the CDI-3D system to interpret¹³ a 3D form in accordance with the digitised 3D data, i.e. data points in (x, y, z) co-ordinates. Figure 4.10 demonstrated the ASCII file specifications and the LASS data which were converted to the ASCII file specifications. The data were transferred from LASS to CDI by means of DAT tape. The CDI-3D extracted and converted these 3D data by means of the 'Wireframes' program. In due course, these data were used for building a realistic virtual sample garment form.

¹¹ The data collected this time were used for all experiments in this study, dated 21 Feb. 1997.

¹² Private conversation with researcher Li (the HUMAG research group, Loughborough University, UK), dated March 1998. See also Jones et al. (1993).

¹³ This techniques was called 'Wireframes' in the CDI-3D system.

Figure 4.10 The original CDI's ASCII file specifications and the LASS data which had been converted for use in the CDI-3D system



In the process¹⁴ of examining these raw data prior to creating the manipulated sample garment form in the CDI-3D system, it was realised that some anomalous data points¹⁵ needed to be removed. Four principles were established to ensure that the sample garment form data were controlled consistently. They were:

- (1) Identifying and stabilising the most crucial control data, i.e. the selected data points should not be changed at any time in order to control the original input 3D form type. These crucial control data referred to the data points which significantly controlled the final garment form. The waist, bust, and shoulder¹⁶ girths were selected because of their significant effects on the fitting degree of the garment form.
- (2) Assessing and modifying the rest of data points using the top view of the cross sections so that the data would be modified only in two axes, i.e. the shape of each cross section of the input garment form. The data points in height direction were usually consistent¹⁷ because they were based on fixed height positions.
- (3) Limiting the groups of data points to be modified each time. Keeping only one group of data points active and the rest 'deactive' in order to simplify data points.
- (4) Deleting the data points which could cause problems for generating a smooth garment form surface. This process was the way to check the input digitised data prior to generating surfaces (see section 4.3.2.3). Finally, it was necessary to justify the modified form in data points as a whole.

¹⁴ Always working with the second copy of the original converted data in order to keep original data.

¹⁵ This was caused by light reflection or distraction during the scanning process.

¹⁶ Refer to the cross section which passed through control shoulder points.

¹⁷ The inconsistent data points were often caused by betrayed lights or body sway while digitising.

4.3.2.3 Generating surfaces in accordance with the input sample garment form data

In order to visualise¹⁸ the input 3D garment form, the CDI-3D 'Surfaces' program (see section 3.4.2, p.3-64 and Appendix 18) represents the 3D data for the sample garment form. This technique made the models (i.e. the 3D garment form in this example) appear solid. Importantly, this technique enabled pattern style lines to be designed onto the 3D garment form surface.

The 'Surfaces' technique was developed by means of an alternative surface co-ordinate system which was known as U and V co-ordinates in the system. The virtual sample garment form was represented by 'UV meshes' which were a collection of surface patch¹⁹ boundaries (for detailed illustration, see Figures 4.11.a~d). By doing this, the data points for the sample garment form were reduced from the original 14,000 (see section 4.3.2.1) to 630 control points for the sample garment form surface.

Although there were different types of surfaces in the CDI-3D's Surfaces program, only the 'Cloud Surface'²⁰ generated a surface for the 3D digitised data. The processes were as follows.

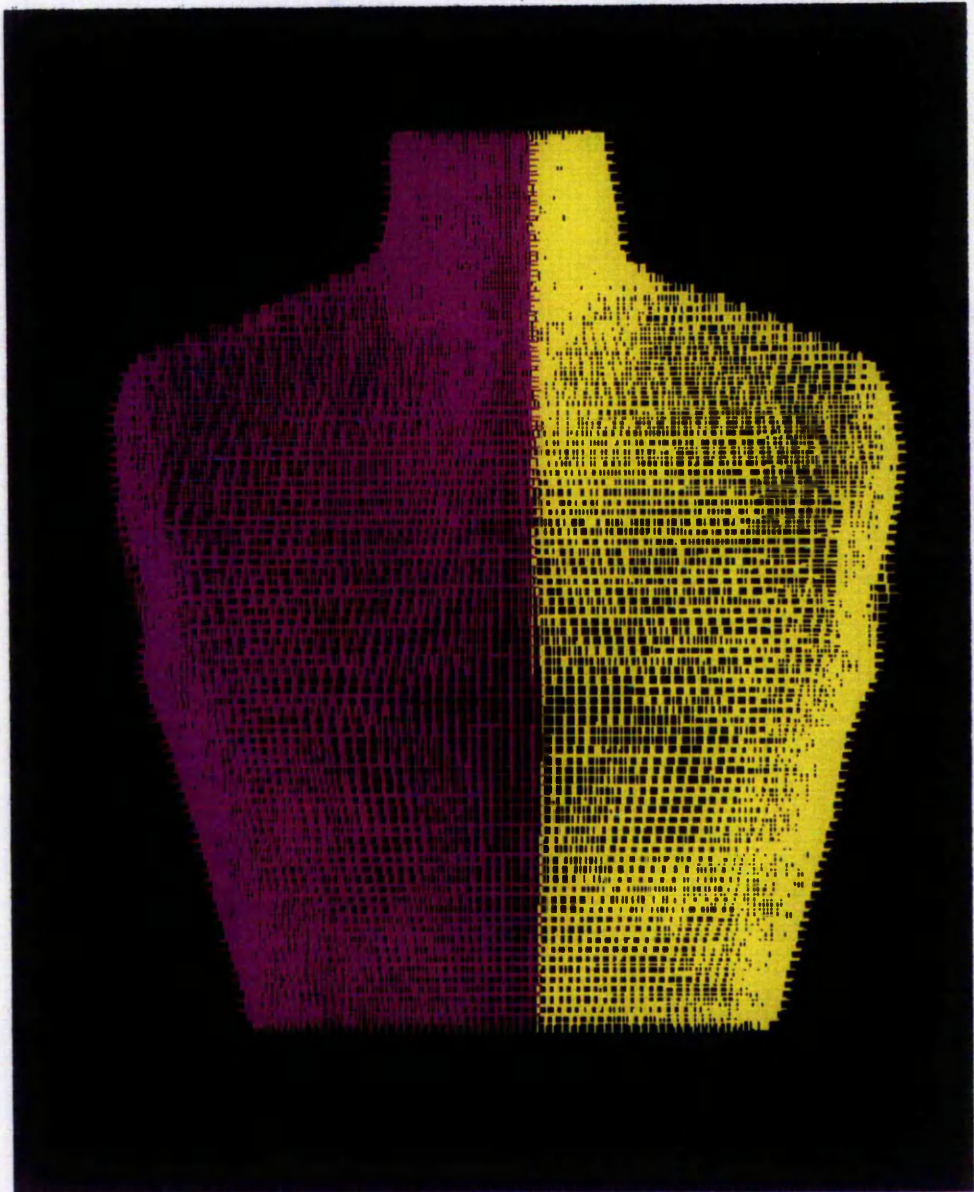
- (1) Only half of the right side of the sample garment form data points was required because only a half front and a half back bodice was used to demonstrate this process. (see Figure 4.11.a).
- (2) The selected data points would define left, right, bottom, and top boundaries for the 3D sample garment form (see Figure 4.11.b). The four-sided control boundaries of the simple geometric form was generated.

¹⁸ See section 3.4.6.1.

¹⁹ 'A collection of a surface bounded by two U and two V mesh lines (patch boundaries). Surfaces may contain one patch or several patches. In the case of multiple patches on a single surface, each patch shares continuity across an internal U or V mesh line with another patch' (CDI, 1995).

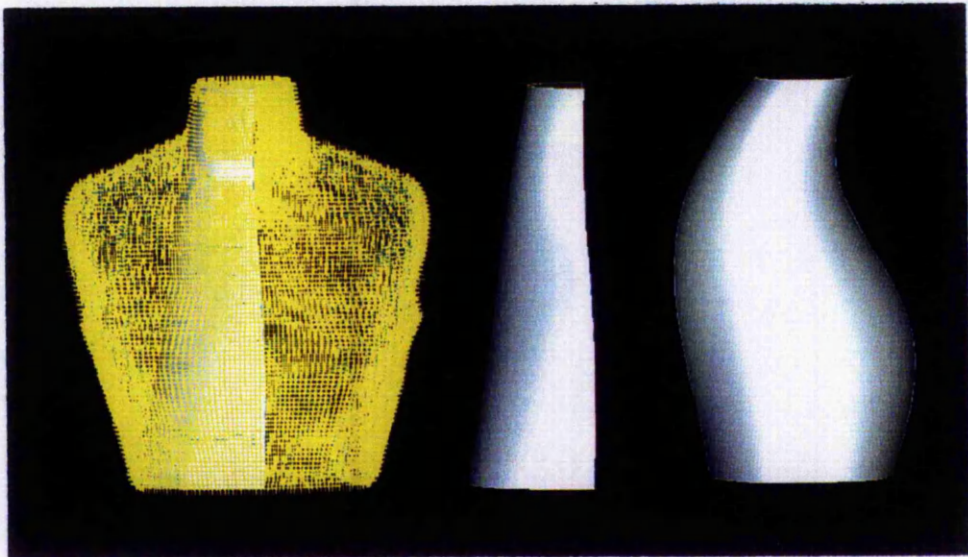
²⁰ 'A surface type created from random wireframe data (digitised data points), region mesh data, or surface polygonal mesh data' (CDI, 1995).

Figure 4.11.a Selecting a more than half of the right side of the sample garment form data in Wireframes



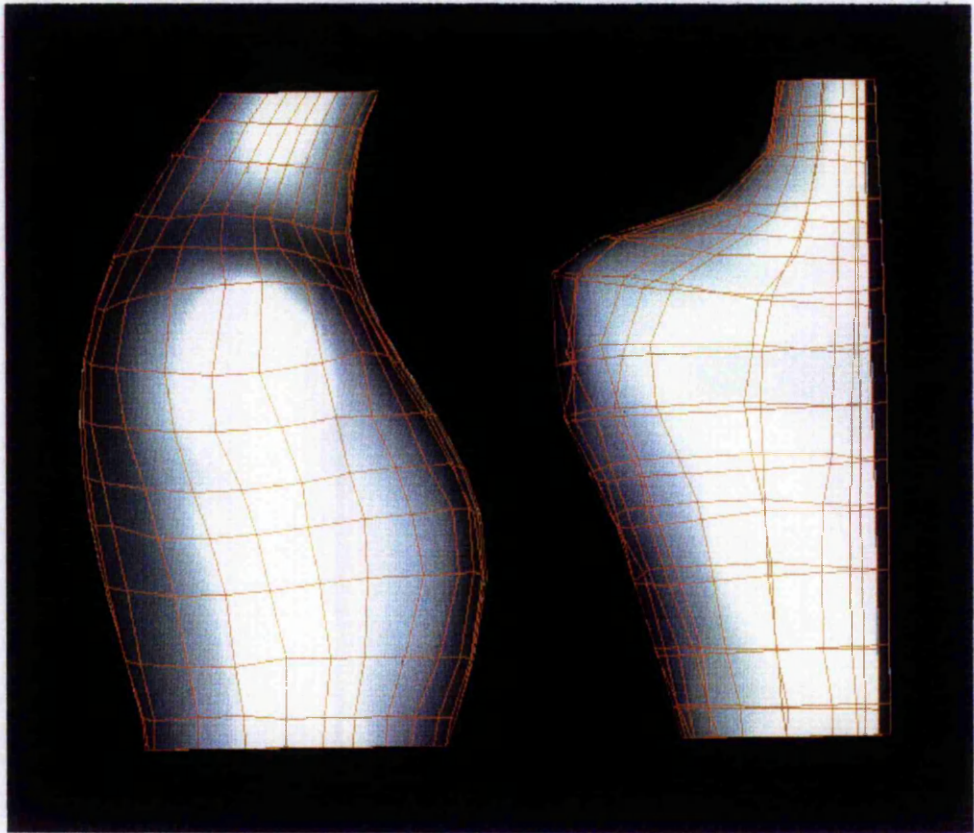
The yellow data points are the original digitised data in Wireframes in the CDI-3D system;
The pink data points are the Wireframe data points which are chosen for generating a 'Surface'.

Figure 4.11.b The sample garment form was generated, in the CDI-3D system, initially in a simple four-sided geometric form



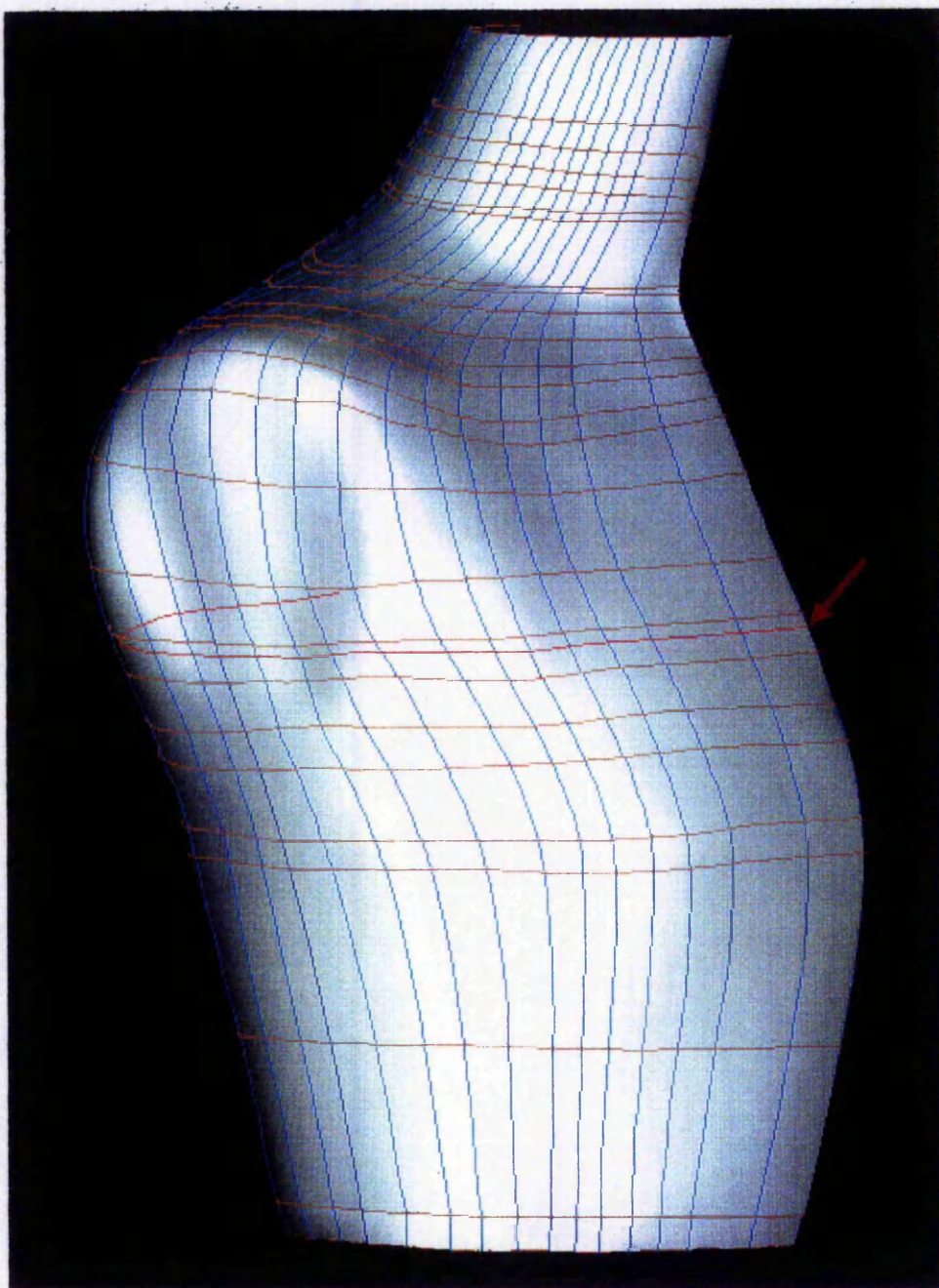
Left is the initially generated 'Surface' (within Wireframes) in a simple four-sided geometric form; the two figures on the right are the front and side views of the generated 'Surface'.

Figure 4.11.c The numbers of the U and V mesh lines depended on the different degrees of the required form curvature



The U and V mesh lines result in many intersected points which can be used to modify the 'Surface'. This can be done by means of modifying one single point or multiple points, as well as proportionally (the right picture illustrates that the U and V mesh lines are overlapped because they can be seen through while modifying).

Figure 4.11.d Some sophisticated areas of the sample garment form, e.g. neck and shoulder areas, needed more U and V mesh lines to shape



The 'blue' indicates the U mesh line; the 'tan' indicates the V mesh line; the highlighted orange line is the 'active' mesh line.

(3) The numbers of the UV mesh lines needed to be determined. This, meanwhile, defined the numbers of the control points for the sample garment form. For the half upper bodice (nape to waist), it was appropriate to set the UV mesh lines to 12 by 12 to begin with and then increase them (see Figure 4.11.c). This was because this mesh set up has shown a smooth surface in conformity with the digitised data points. Then, modify UV mesh lines in the sophisticated areas, e.g. in the neck and shoulder areas. In practice, the more severe the shape changed, the more UV mesh lines that were required, e.g. the front neck and shoulder areas (see Figure 4.11.d).

The key principle for modifying the form surface was *not* to change the control boundaries²¹ (see step 2, in section 4.3.2.3). The modification inevitably affected the construction of the UV mesh lines, but it did not significantly affect the appearance of the smooth form surface.

Up to now, the generated sample garment form was still presented as likely to be a basic garment form in the system. Generating a 'look-a-like' garment stand or garment form was not a time consuming process when the operator became used to it. This was because no control measurements' information was provided for the generated garment stand or garment form. However, in order to confirm all the control measurements as identical to the one in the real world would involve in even more complex modifications to the generated garment stand or sample garment form (see next section 4.4).

²¹ This referred to the four boundaries which were selected to generate the surface.

4.4 Making the Two Sample Garment Forms Identical

Having generated a *similar* sample garment form in the virtual world, it was then essential to ensure that it was controlled to be identical to the one in the real world. The greatest challenge occurred when all the primary and secondary control measurements on the real and virtual sample garment forms required, in practice, to be consistent with each other. This process was likely to be a made-to-measure garment constructed in three dimensions; all measurements were taken directly from the sample garment form, itself.

It was also necessary to inquire, if all the pre-defined primary and secondary control measurements on the real and virtual garment forms were controlled to be consistent to each other, would the other newly conducted measurements on the comparatively identical distance between the real and virtual worlds be the same ?

The investigation in this section was divided into four strands: first, controlling consistent primary and secondary control measurements; second, shaping the neck and armscye bases; third, selecting the two convex measurements to assist the 3D garment form control; finally, verifying the consistency.

4.4.1 Consistent Primary and Secondary Control Measurements

The classification of the primary and secondary control measurements used by this study was made in section 4.2.3 (see Figures 4.6 and 4.7, pp.4-16 ~ 17). In consideration of the human factor in the real world, the acceptable inconsistency of the measurements was defined within 0.5 mm. This was because the researcher's visual judgement could only reach this level. This meant that if the inconsistent measurement between the real and virtual worlds was under 0.5 mm, it would be regarded as *consistent*, although more precise measurements could be recognised by the CDI-3D system. Having defined the acceptable level of inconsistent measurements between the real and virtual sample garment form, all the required measurements were hence controlled consistently.

4.4.2 The Neck and Armscye Shapes

Although there were pre-defined control landmarks, i.e. three for the neck base and four for the armscye base (see Figure 4.8, p.4-19), there were general principles to be followed when shaping these two measurements.

Primarily, the front and back neck points needed to be a right angle along the neck shape, itself, which was to ensure the smoothness of the shape after being 'mirrored'. Secondly, the back neck base was bent to correspond with the blade area. Finally, the area between the front and under armpit points were usually curved more than the back armscye because arm movement was mostly forwards.

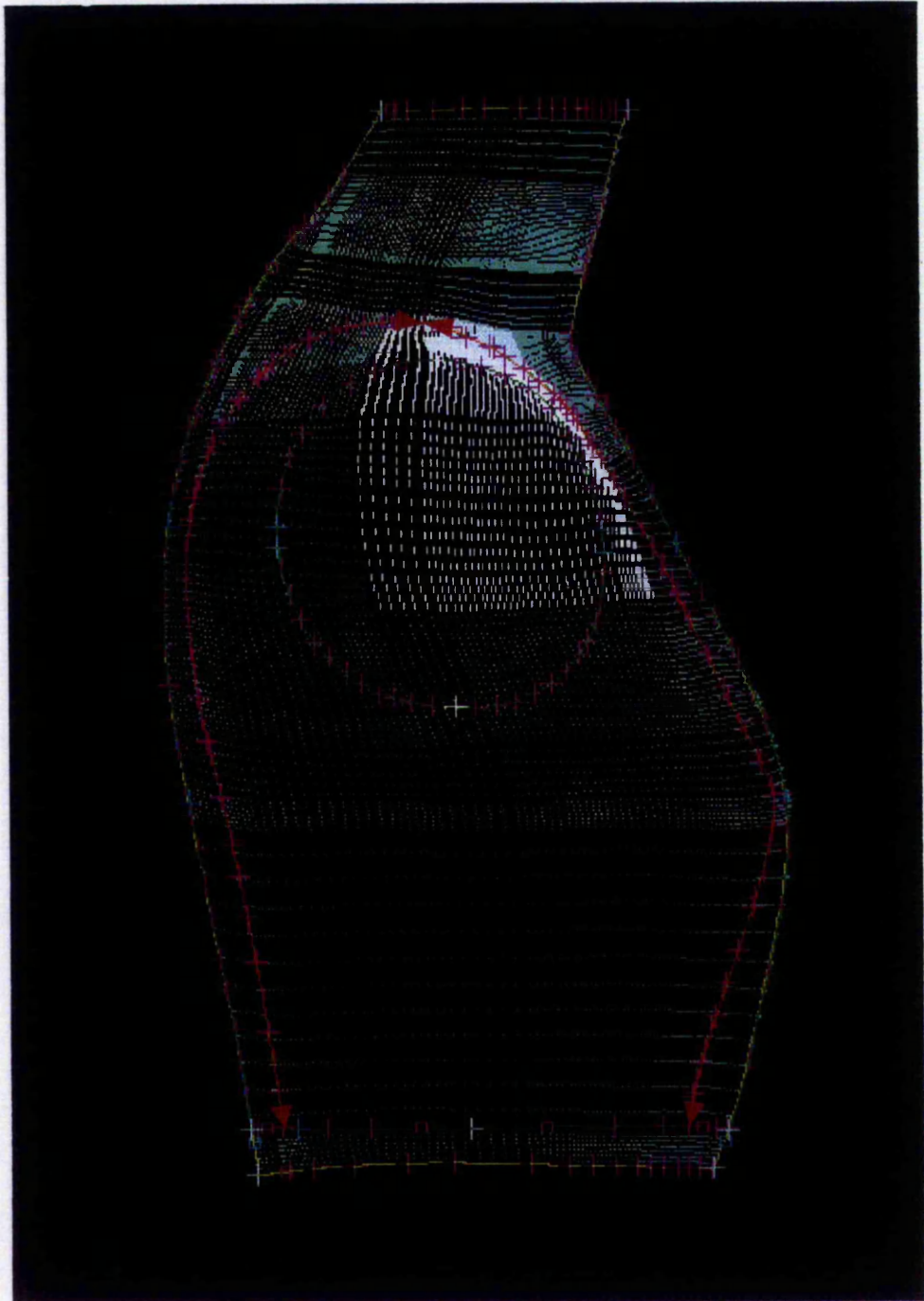
4.4.3 The Two Convex Control Measurements

The convex control measurement referred to the measurement which would cross over the most prominent area of the sample garment form. They were: from mid shoulder crossing over bust to the front waist and from mid shoulder crossing over blade area to the back waist (Figure 4.12).

Having made the primary and secondary control measurements within the consistent level, it would require another control measurement which, in practice, gave the required full length of the sample garment form. In turn, they had to cross over the most convex areas of the front and back sample garment form, e.g. the blade and the bust areas. However, the back convex control measurement was constructed very close to the blade point but along with the smooth curvature.

The establishment of these two control measurements, both in the real and virtual worlds, would be seen as seams which divided the front and back foundation garment form into two patterns. These two control measurements would be used as guides to control and smooth the 3D garment form.

Figure 4.12 The two convex measurements used to assist in controlling the sample garment form



The side view of the two convex measurements; one from mid shoulder crossing over the bust point to the front waist level, the other one crossing over the blade area to the back waist level.

4.4.4 Verifying the Consistency

Having controlled all the processes described above, the real and virtual sample garment forms were seen as consistent with each other (Figure 4.13). However, it would be more convincing if a new measurement which was not controlled within the whole process could also be confirmed as consistent between the real and virtual worlds in practice.

Figure 4.14 illustrated that the inconsistency of the three measurements between the real and virtual sample garment forms, which were not identified as control measurements within this study, was respectively 0.5, 0.7, and 0.3 mm. Although one of the inconsistencies was slightly over the acceptable level which this study defined previously, this provided convincing evidence that the real and virtual sample garment forms could be regarded as consistent in practice. The final control measurements of the virtual sample garment form are listed in Figures 4.15-16.

Figure 4.13 A comparison of actual and virtual sample garment form measurements

Unit : centimetre

	Real sample garment form	CDI-3D sample garment form	Differences
(Primary control measurements)			
Centre back	40.70	40.70	0.00
Across back*	19.60	19.65	0.05
Armhole width	13.70	13.67	0.03
Centre front	35.70	35.69	0.01
Across front bust width*	19.00	19.02	0.02
(secondary control measurements)			
Back shoulder width*	19.80	19.77	0.03
Front shoulder width*	18.55	18.58	0.03
Back bust girth*	22.60	22.63	0.03
Front bust girth*	25.35	25.39	0.04
Back waist girth*	17.70	17.68	0.02
Front waist girth*	18.65	18.67	0.02
Shoulder length	12.55	12.56	0.01
Underarm to waist	18.55	18.52	0.03
Mid-shoulder to back waist	41.40	41.40	0.00
Mid-shoulder to front waist	41.00	40.97	0.04
Across front*	17.65	17.63	0.02

Note 1 Those figures with an asterisk in the end refer to the 'half measurements', i.e. the measurements for only a half pattern, another half is often 'mirrored'.

Note 2 The acquisition of the control measurements was in reference to Figures 4.5-7. The differences of the measurements between the real and virtual worlds were controlled within 0.05 cm.

Figure 4.14 Verifying the consistency of the foundation garment form in the real and virtual worlds using the three un-controlled measurements

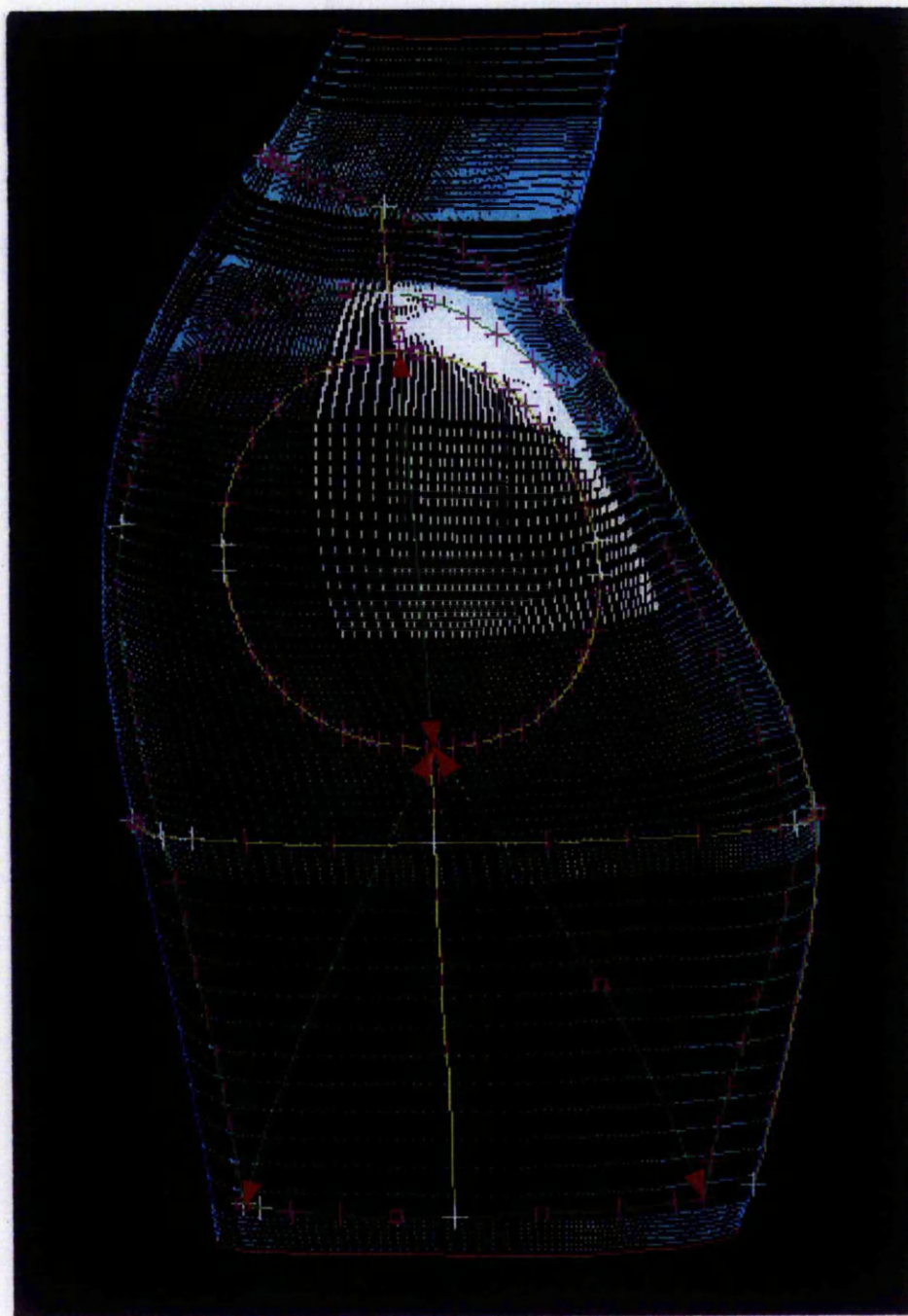


Figure 4.15 The primary control measurements of the sample garment form controlled in the CDI-3D system

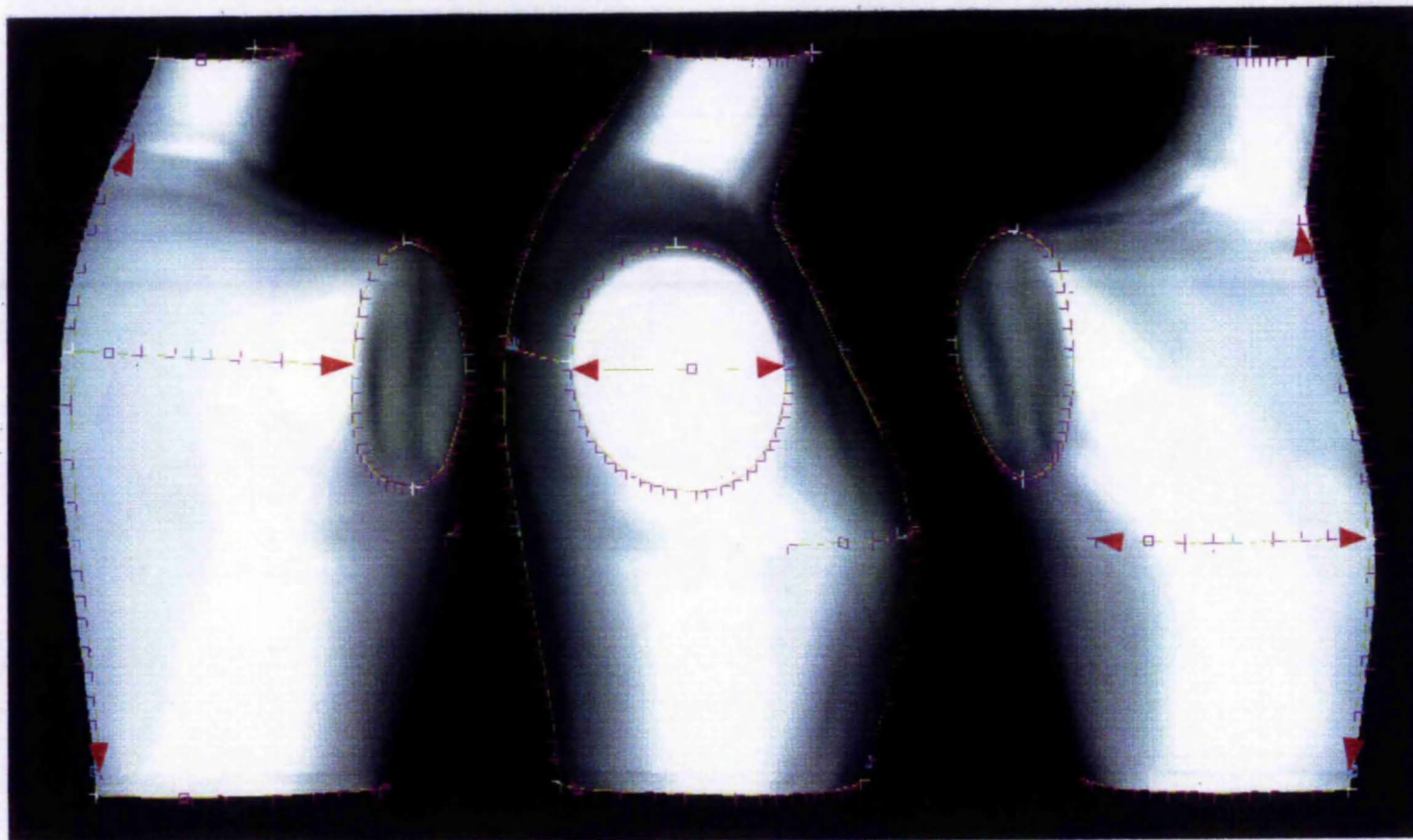
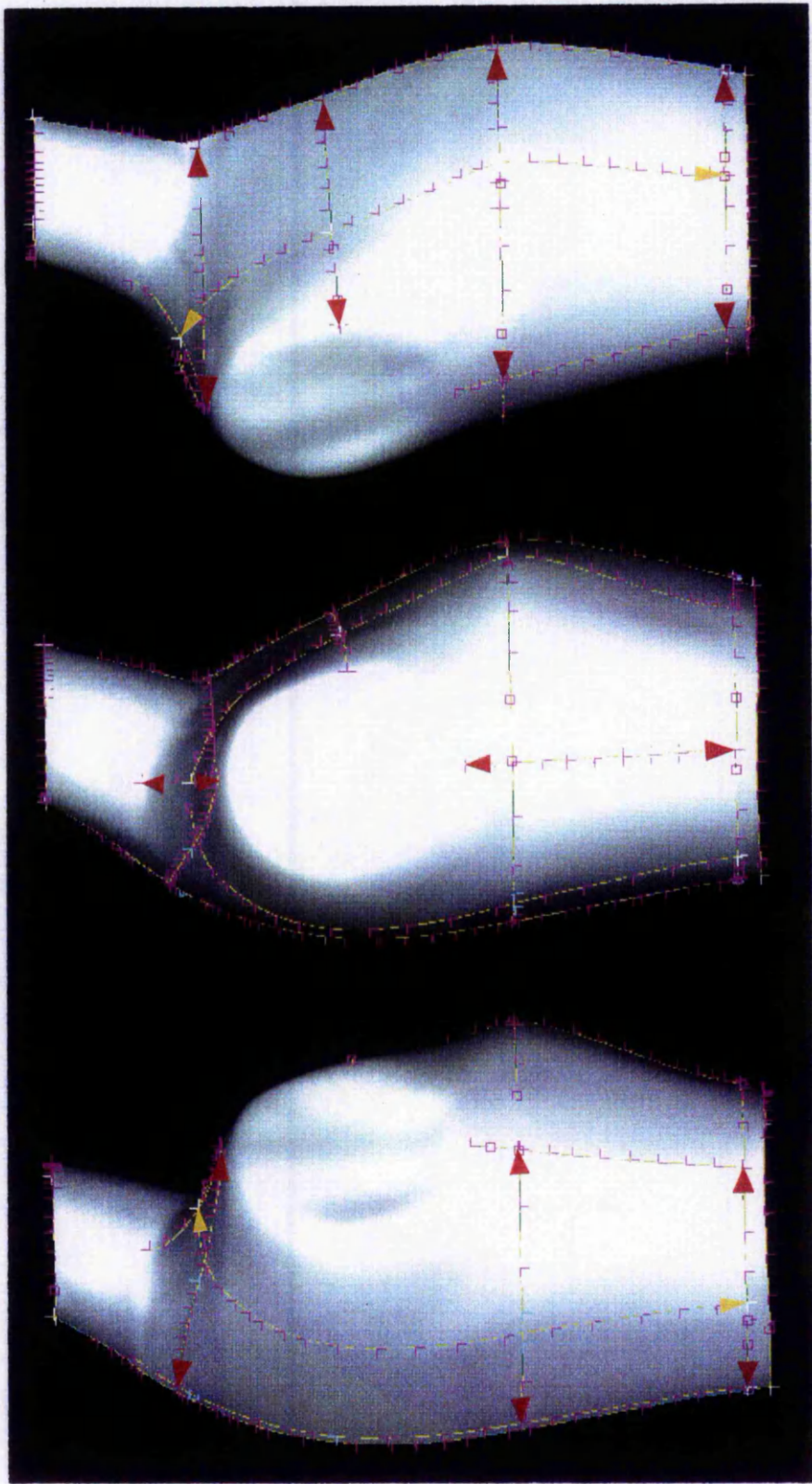


Figure 4.16 The secondary control measurements of the sample garment form controlled in the CDI-3D system



4.5 Setting Up a Process to Obtain a Consistent Manual Pattern

It should be acknowledged that, in manual pattern making, the argument concerning consistent garment patterns occurred mainly because of the individual use of the term fit. This was caused fundamentally by the distribution of diverse garment eases. Having established the sample garment form in a solid type (i.e. including ease) in the real world (see section 4.2), 3D manual pattern making was therefore based on 'contact-fit' toiling. This method of manual pattern making not only eliminated one of the most problematic subjective factors, but also provided a better way of judging manual pattern consistency.

The second argument about manual pattern making was the individual empirical experience of making patterns. This could involve two factors: the fabric used and the human errors which happen in the process of constructing patterns. In order to solve these two problems, the fabric was pre-defined and controlled consistently by specific treatments; the problem of human error in constructing patterns was reduced as much as possible by conducting and averaging twenty sample results respectively using paper and calico to obtain a 'relatively objective' pattern (see section 4.5.4).

The third argument concerned which foundation patterns could also be developed consistently in four panels by passing a seam over the most prominent areas, i.e. blade and bust points. This challenged whether the 'traditional method of constructing a 2D basic bodice block' in two panels for a close fitting garment would also be applicable to the garment form of solid type. In turn, if the garment patterns which were manually toiled from the real solid garment form were not consistent, themselves, an alternative method for generating consistent electronic patterns was required which took account of the insight of 3D manual pattern construction gained from practical experiments.

By taking these arguments into account, this section analyses the process to control a consistent manual pattern in order to obtain a relatively objective foundation pattern for later comparison with an electronically flattened foundation pattern.

In order to produce consistent manual patterns, it was essential to control consistently the related variables such as the calico used, the pattern construction, and the process of manual toiling (see sections 4.5.1~3). Meanwhile, to ensure a consistent pattern stability, manual patterns needed to be made in multiples so that an averaged pattern shape could be obtained more objectively. This meant that all the manually toiled patterns had to be inputted into the AccuMark 2D-PDS using the linked 2D digitiser (see sections 4.5.5~6).

4.5.1 Controlling the Calico

Calico is almost a generic term which, in practice, consists of many different kinds in terms of fibre contents, yarn constructions, fabric weights, thickness, and shearing quality. In order to represent fabric drape in a 3D CAD environment, these fabric properties need to be interpreted by the computer. There are two major fabric testing methods: 'FAST' (Fabric Assurance by Simple Testing) and 'KES' (Kawabata Evaluation System for Fabric). This study is limited in demonstrating fabric testing and properties in order to focus specifically on pattern making.

The original medium weight calico selected did not have a consistent fabric construction, i.e. the warp and weft yarns were not constructed in a right angle. This was often caused by different tensions in the warp and weft directions or the calico starching process. 'Yarn-pulling' and steam-ironing the calico were the two processes used to correct this problem.

The yarn-pulling process was sampled using 2.5, 5, and 10 cm as a square unit in order to evaluate whether this treatment to the calico would affect the toiling solution. It was found that the '5 x 5' square unit was most suitable for the process because too many yarn-pulling times would soften the calico, whereas too wide an interval of the indication of the warp and weft yarn construction would not give enough information.

4.5.2 Stabilising Pattern Construction

The main criterion of determining the pattern construction for the 3D garment form was to keep the best stability and consistency of manual pattern making. This was because the manually toiled pattern would be used finally as convergence criteria to assess the electronically flattened patterns. Hence, manual pattern stability became the most crucial element to be controlled in stabilising pattern construction. In order to obtain this attempted manual stability, four considerations were taken into account.

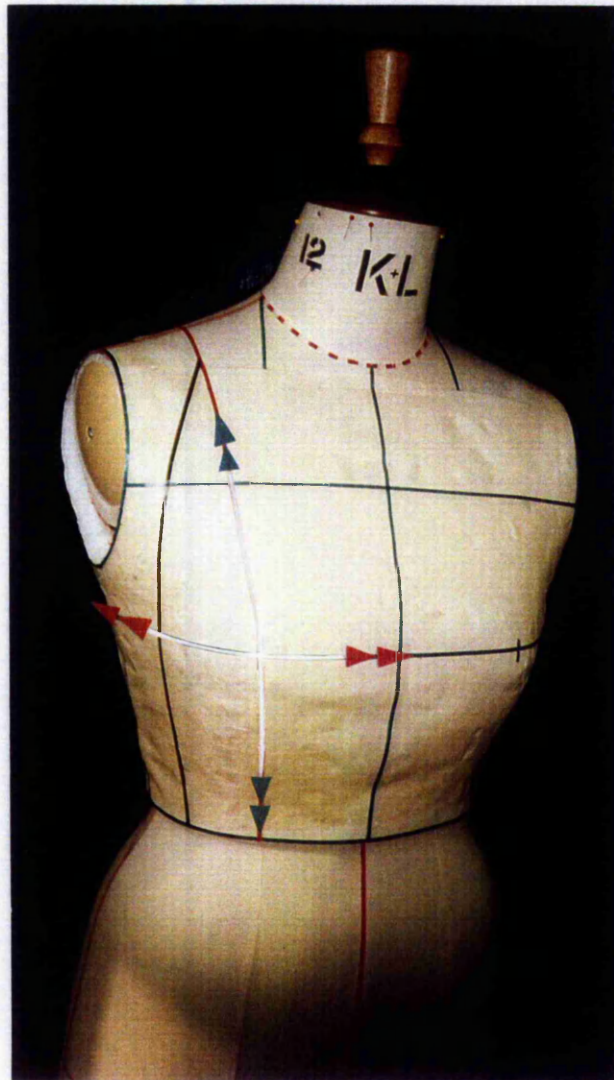
First, there were two possibilities which could make a garment form close fitting, i.e. dart and seam. The first possibility was abandoned after the first trial. The reason for this was that the end point of a dart often resulted in an unsmooth shape on the 3D 'contact-fit' (i.e. skin-tight) garment form with toile. This was seen as inappropriate for adaptation by this study as it is concentrated mainly on pattern consistency. The second possibility, i.e. seam, was therefore selected for the practical experiments in Chapter Five.

Second, the foundation pattern construction had to take the consistency of the manual process into account. The priority was to determine the type of pattern construction which would make it easier and consistent for manual pattern making in three dimensions. Taking these factors into account, two widely used methods of constructing a close fitting bodice block were tried on the created 3D garment form. A trial was made in which the front seam was constructed close to the front armpit point. This type of construction was abandoned after a few trials because first, the seam curvature was too various to be controlled consistently and second, it caused more inconsistency than another type due to more 'dual bending'²² characteristics constructed around this area (Figure 4.17).

Third, the selection of the seam was adapted from the two-dart construction of the traditional style of close fitting bodice block construction (see sections 2.4~5). The four seams were constructed, one at the side bodice, one at the shoulder, and the other two passing over the most convex areas at the front and back bodices crossing the 'mid

²² E.g. the surface of a cone is bent in a single direction, whereas the sphere's is bent in a dual direction. The practical example in relation to the garment form surface is the bust area on the 3D garment form.

Figure 4.17 One of the dual-bending characteristics around the bust area of the sample garment form has been released by the seam construction



shoulder' area²³. This meant that the right half garment form was divided into four panels by the shoulder, side, back, and front seams.

Finally, to ensure each pattern on the sample garment form stabilised, the direction of the grain was specified on each pattern to assist the manual toiling process more consistently. The four grains²⁴ were specified as: the centre back, the side-back pattern centre, the side-front pattern centre, and the centre front.

Figure 4.18 illustrates the pattern construction which was finally selected as a foundation pattern for experimental comparison in Chapter Five. The reasons for choosing this type of pattern construction were: first, it caused less inconsistency during the manual toiling process; second, it cut along the most convex dual-bending areas, i.e. the blade and bust which are essential guides for full bodice garment length; finally, knowledge of this type of construction has been accumulated by generations of garment pattern making experts.

4.5.3 Controlling a Consistent 3D Manual Pattern Toiling Process

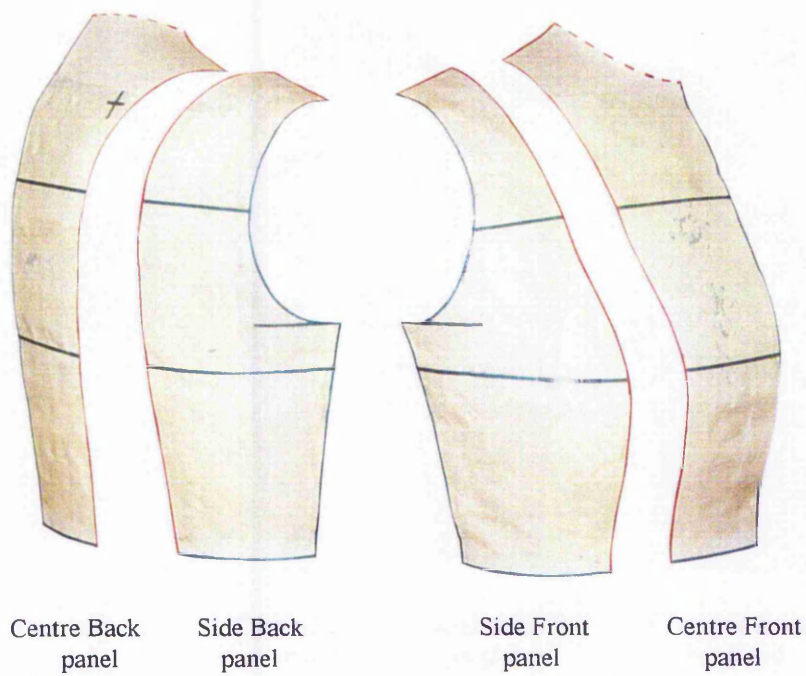
Manual pattern toiling is a craft and often individual. In order to control a consistent process of toiling foundation patterns three-dimensionally, three stages were undertaken.

For the first stage, each calico sample was cut approximately in '50 x 35' cm. This calico size was approximately for two pattern panels, i.e. either for the front or the back bodice. A warp and a weft yarn was pulled at every 5 cm interval. Each calico sample was stretched in 45-degree and 135-degree bias direction to correct its construction, then it was steam-ironed to smooth the creased surface caused by the yarn-pulling process. Lastly, the calico sample was left flat and relaxed for over twenty-four hours before experiments. This was to provide a better consistency of the fabric construction.

²³ This selection was because of its practical use in the mass garment industry (see section 2.6). The measurement mid-shoulder to back waist was seen as equal to the measurement 'nape to waist'.

²⁴ Placing the centre front and back seams on the straight grain were used widely by 3D toiling experts (Kunick, 1984; Mee and Purdy, 1987; Silbergberg and Shoben, 1991; Stanley, 1991) to begin a basic toiling process; however, for even back waist suppression, the centre back line may be shaped.

Figure 4.18 The pattern construction which was selected for later experiments



For the second stage, each pattern was toiled by matching consistently the fabric grain along the centre grain line of the 3 mm wide tape marking on the 3D garment pattern. The marked centre grain line would be tremendously helpful to ensure pattern stability in toiling manually a 3D pattern to a 2D pattern.

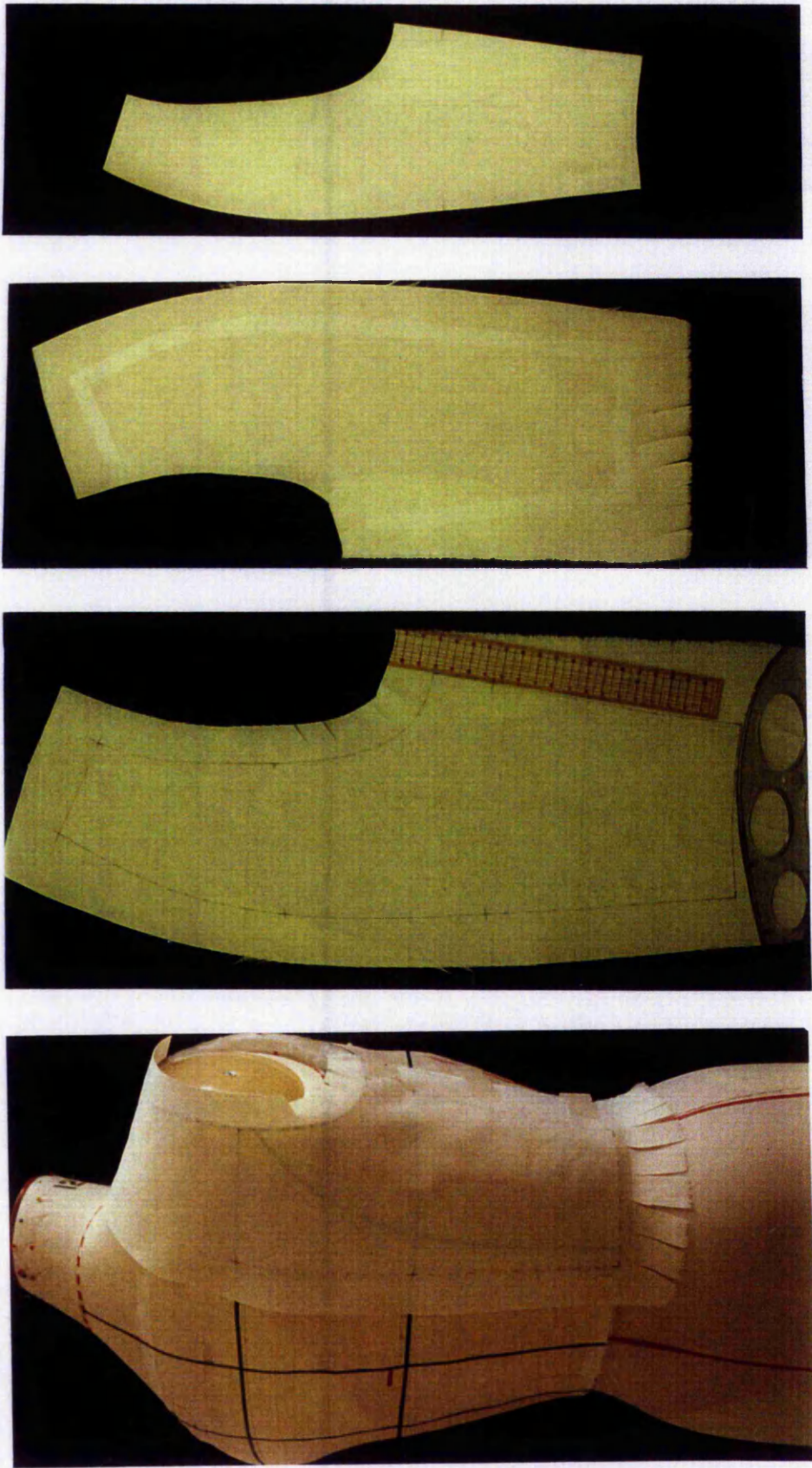
Finally, to eliminate the manufacturing factor which would entail more variables for producing garment patterns, the sewing process of assembling patterns was ignored temporarily in this study. Surgical tape was used, instead. This special treatment not only coped with the seam allowance problem, but also eliminated the possible inconsistency which was caused by seam stretching during the stitching process and by ironing calico patterns after they had been sewn together.

Having controlled the related requirements consistently, paper and calico were used to toile the foundation pattern directly on the solid sample garment form. The paper pattern was used to compare with the calico patterns regarding pattern inconsistency which could be caused by fabric bending and individual manual process factors. An example of the toiling process for one of the foundation patterns is illustrated in Figure 4.19. Basic principles were: matching the calico on the sample garment form along with the pre-defined grain line and pencil marking the pattern outline on the calico; flattening calico on the work table and refining the pencil marks; taping the back side of the calico at the centre pencil marks using surgical tape to stabilise the pattern and to prevent the fraying of the calico; finally, cutting off the surplus calico.

4.5.4 Constructing 160 Pieces of Paper and Calico Foundation Patterns

Each of the 4 patterns was made twenty times by the same person, so that any inconsistency could be averaged out and a relatively objective pattern could be obtained. The foundation patterns consisted of 80 pieces of paper and 80 pieces of calico. The process was intended to demonstrate that a paper pattern could be produced without any problematic distortion in relation to fabric construction; however, it was found that paper patterns were less consistent than calico patterns because of the fabric bending effect.

Figure 4.19 The toiling process of obtaining the foundation pattern



The 160 pieces of foundation patterns were constructed as individual pattern pieces following precisely the specified pattern outlines on the sample garment form. The four foundation patterns were labelled as follows: centre back (CBACK), side back (SBACK), side front (SFRONT), and centre front (CFRONT) panels (see Figure 4.17), bearing in mind that each of the four patterns has to be referred to as all paper or all calico patterns. At this stage, the research considered that, before averaging, any set of four patterns could, after modification, construct the final complete foundation patterns.

4.5.5 Inputting Paper and Calico Patterns into the AccuMark 2D-PDS

In order to enable the comparisons of the paper and calico patterns, all the patterns needed to be inputted or transferred into an existing 2D-PDS. The later comparative results with electronically flattened patterns required that the 2D-PDS selected could accept electronically flattened pattern data from the CDI-3D system. The AccuMark 2D-PDS was therefore selected. The process of transferring a CDI-3D electronically flattened pattern into the AccuMark 2D-PDS is stated in section 4.6.

4.5.6 Averaging Paper and Calico Patterns

4.5.6.1 Averaging pattern edge measurements and pattern areas

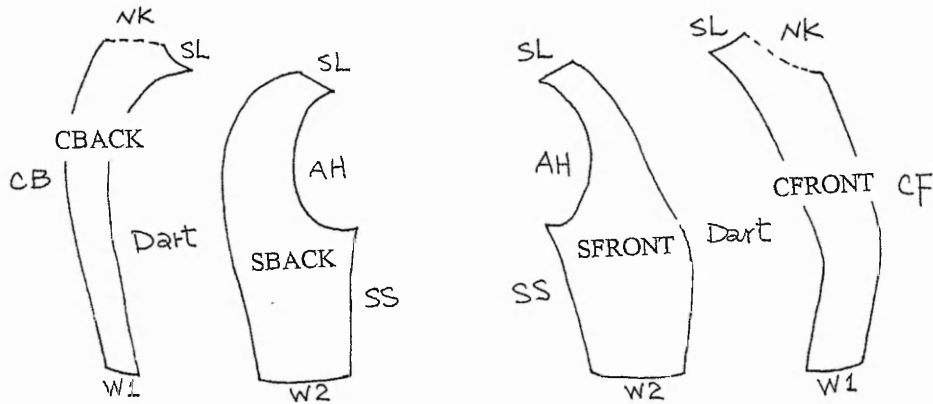
AccuMark 2D-PDS, from Gerber Garment Technologies, is an industry standard system. It provides a means of accurate calculation and enables pattern comparisons to be made. Using the pre-defined stabilised pattern construction, each piece of pattern consisted of five sides as pattern edges; a pattern area was then framed by these five pattern edges. The averaging process was constructed to deal with these two main elements. The averaged value was used as a mean to compare each individual piece of the twenty foundation patterns. First, the first and last 25 % of the inconsistent pattern edge measurements and areas were abandoned. By doing this, only ten of each pattern

periphery were seen as consistent. Second, the more consistent foundation pattern was selected out of the ten by juxtaposing all the inconsistencies occurring in each. Figures 4.20-21 showed twenty calico and paper foundation patterns measured by AccuMark. Figures 4.22-23 illustrated the inconsistency of the calico and paper foundation patterns compared to the mean.

4.5.6.2 Checking the final averaged pattern shape

The four pattern pieces selected for foundation patterns to be compared with the electronically flattened foundation patterns were CBACK-10, SBACK-16, CFRONT-17, and SFRONT-20. To determine the final averaged pattern shape there were two processes to be addressed. The primary selection process gave more than one foundation pattern because some patterns were almost identical to each other. Therefore, a secondary selection had to be made in order to determine the final foundation pattern. Also, the four finally selected foundation patterns were modified in two dimensions. This included checking each two adjacent pattern peripheries and the matching pattern angles. The modification was done in the AccuMark 2D-PDS. The final modified four patterns were then assembled using surgical tape (Figure 4.24).

Figure 4.20 The twenty calico foundation patterns measured by AccuMark



CFRONT

SFRONT

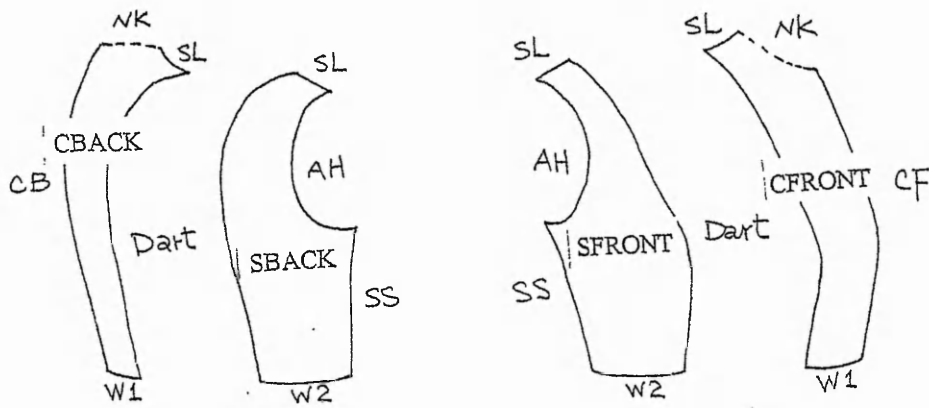
	CF	NK	SL	Dart	W1	Area	Periphery	Dart	SL	AH	SS	W2	Area	Periphery
1	35.84	10.81	6.38	41.38	7.66	399.97	102.07	41.46	6.19	22.07	18.59	10.96	403.35	99.27
2	35.71	10.96	6.39	41.29	7.78	399.78	102.13	41.12	6.27	22.07	18.64	11.03	401.58	99.13
3	35.87	10.93	6.49	41.15	7.65	399.35	102.09	41.21	6.06	22.15	18.45	11.03	399.22	98.89
4	35.74	10.95	6.46	41.34	7.58	400.04	102.07	41.27	6.19	21.94	18.64	11.13	402.83	99.16
5	35.79	11.01	6.44	41.25	7.65	400.10	102.14	41.25	6.14	22.14	18.56	11.09	403.06	99.18
6	35.92	10.92	6.50	41.23	7.63	400.41	102.19	41.36	6.19	22.03	18.58	11.22	402.50	99.32
7	35.74	10.98	6.46	41.36	7.63	397.88	102.17	41.32	6.20	22.16	18.74	10.89	399.72	99.31
8	35.79	10.99	6.38	41.35	7.68	396.88	102.20	41.19	6.13	22.40	18.69	11.05	401.79	99.46
9	35.81	10.91	6.45	41.25	7.60	397.23	102.03	41.33	6.31	22.06	18.62	10.86	401.18	99.17
10	35.84	10.95	6.44	41.22	7.63	398.20	102.08	41.35	6.15	22.14	18.62	10.96	401.84	99.22
11	35.86	10.96	6.50	41.25	7.63	399.08	102.20	41.35	6.21	22.07	18.70	11.00	401.06	99.34
12	35.92	10.94	6.58	41.22	7.65	398.79	102.32	41.30	6.16	22.27	18.70	11.09	403.96	99.53
13	35.94	10.98	6.58	41.21	7.71	399.96	102.41	41.31	6.08	22.28	18.62	11.15	402.27	99.44
14	35.81	10.97	6.54	41.26	7.58	397.80	102.17	41.29	6.15	22.20	18.52	11.06	401.68	99.22
15	35.79	10.96	6.56	41.25	7.61	398.57	102.16	41.33	6.10	22.22	18.58	11.07	401.18	99.30
16	35.74	10.85	6.29	41.29	7.65	396.60	101.84	41.25	6.13	22.21	18.63	11.14	403.67	99.34
17	35.81	10.91	6.46	41.26	7.63	397.50	102.07	41.24	6.08	22.23	18.58	11.10	402.07	99.23
18	35.79	10.92	6.47	41.30	7.58	398.00	102.07	41.18	6.16	22.15	18.66	11.04	400.32	99.20
19	35.89	10.85	6.46	41.27	7.63	397.70	102.10	41.41	6.18	22.13	18.64	11.05	402.20	99.40
20	35.86	10.92	6.58	41.25	7.66	396.49	102.28	41.34	6.17	22.15	18.59	11.07	403.99	99.32
AVG	35.82	10.93	6.47	41.27	7.64	398.52	102.14	41.29	6.16	22.10	18.62	11.05	401.96	99.27

CBACK

SBACK

	CB	NK	SL	Dart	W1	Area	Periphery	Dart	SL	AH	SS	W2	Area	Periphery
1	40.79	8.75	6.35	41.79	6.99	402.61	104.67	41.58	6.27	23.02	18.59	10.64	423.79	100.11
2	40.69	8.47	6.28	41.63	6.94	398.53	104.01	41.50	6.28	23.01	18.55	10.68	425.66	100.02
3	40.77	8.74	6.28	41.70	7.04	404.23	104.53	41.55	6.18	22.97	18.43	10.65	425.63	99.78
4	40.72	8.59	6.29	41.70	7.09	401.05	104.38	41.58	6.09	22.97	18.53	10.69	425.46	99.86
5	40.74	8.44	6.46	41.82	7.04	405.64	104.50	41.71	6.17	22.93	18.53	10.62	425.48	99.96
6	40.69	8.55	6.37	41.49	7.09	404.07	104.19	41.50	6.32	22.91	18.57	10.67	424.70	99.97
7	40.72	8.40	6.36	41.88	7.14	404.87	104.50	41.55	6.29	23.04	18.65	10.60	424.48	100.13
8	40.72	8.38	6.41	41.86	7.17	403.56	104.54	41.70	6.15	22.99	18.61	10.58	425.06	100.04
9	40.74	8.39	6.46	41.71	7.06	403.74	104.35	41.84	6.18	22.83	18.59	10.65	423.49	100.09
10	40.77	8.53	6.40	41.78	7.11	405.03	104.59	41.72	6.10	22.88	18.63	10.48	424.30	99.82
11	40.74	8.36	6.46	41.82	7.06	403.21	104.45	41.64	6.14	22.99	18.62	10.48	422.89	99.86
12	40.79	8.36	6.40	42.10	7.14	405.99	104.80	41.77	6.13	22.91	18.63	10.60	425.10	100.03
13	40.79	8.60	6.39	41.90	7.04	405.02	104.73	41.71	6.16	22.97	18.65	10.67	426.68	100.17
14	40.72	8.48	6.37	41.99	6.99	403.93	104.55	41.76	6.27	22.87	18.55	10.64	425.07	100.09
15	40.74	8.53	6.41	41.97	7.09	406.05	104.75	41.78	6.13	22.89	18.61	10.56	424.90	99.96
16	40.79	8.43	6.32	41.99	7.07	406.73	104.60	41.71	6.18	22.90	18.58	10.64	423.78	100.01
17	40.74	8.53	6.40	41.95	7.07	405.44	104.69	41.72	6.13	23.03	18.58	10.69	424.70	100.13
18	40.74	8.44	6.34	41.74	7.01	403.47	104.28	41.99	6.08	22.88	18.62	10.65	424.77	100.12
19	40.89	8.35	6.36	42.02	7.04	407.02	104.66	41.46	6.19	23.00	18.53	10.61	423.42	99.94
20	40.77	8.40	6.37	41.94	7.04	403.07	104.51	41.79	6.10	22.94	18.61	10.64	424.53	100.09
AVG	40.75	8.49	6.37	41.84	7.06	404.16	104.51	41.68	6.18	22.95	18.58	10.62	424.69	100.01

Figure 4.21 Twenty paper foundation patterns measured by AccuMark



CFRONT

SFRONT

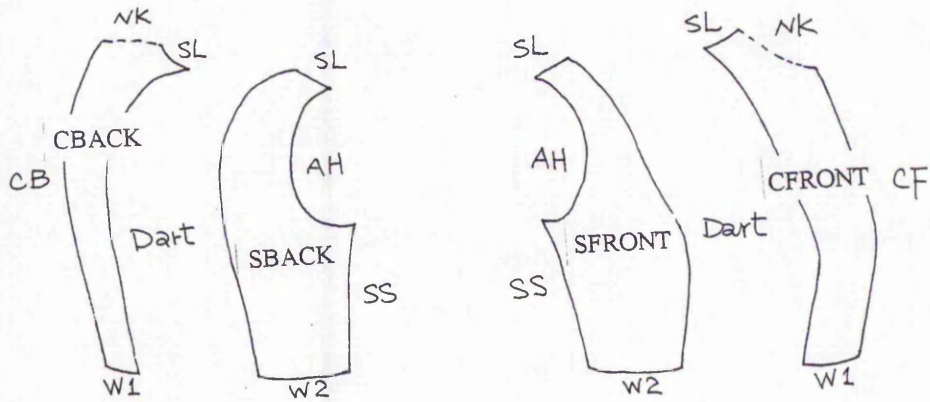
	CF	NK	SL	Dart	W1	Area	Periphery	Dart	SL	AH	SS	W2	Area	Periphery
1	35.79	11.06	6.46	41.45	7.63	400.83	102.39	41.29	6.11	22.32	18.67	11.08	402.90	99.47
2	35.84	11.00	6.38	41.50	7.61	399.75	102.33	41.35	6.16	22.20	18.66	11.03	400.87	99.41
3	35.79	10.93	6.38	41.50	7.66	399.83	102.27	41.40	6.16	22.19	18.63	11.11	402.31	99.49
4	35.81	11.02	6.41	41.43	7.71	400.77	102.40	41.40	6.16	22.10	18.63	11.08	401.66	99.37
5	35.86	11.00	6.39	41.34	7.56	397.17	102.16	41.50	6.13	22.12	18.61	11.04	400.74	99.39
6	35.84	11.03	6.40	41.45	7.59	399.50	102.31	41.35	6.19	22.19	18.65	10.99	402.12	99.30
7	35.79	11.04	6.4	41.52	7.59	399.53	102.34	41.39	6.12	22.12	18.63	10.97	402.51	99.23
8	35.84	10.99	6.44	41.49	7.58	399.78	102.34	41.63	6.17	22.03	18.67	10.94	402.78	99.44
9	35.79	11.03	6.39	41.44	7.51	399.14	102.15	41.40	6.18	22.17	18.65	11.16	404.31	99.59
10	35.69	11.06	6.47	41.51	7.58	400.30	102.32	41.19	6.15	22.22	18.67	11.09	401.95	102.32
11	35.79	10.98	6.38	41.48	7.53	399.04	102.09	41.49	6.11	22.16	18.68	11.06	402.83	99.49
12	35.86	10.94	6.41	41.52	7.51	399.14	102.24	41.50	6.13	22.05	18.69	11.14	403.49	99.52
13	35.79	11.02	6.45	41.51	7.56	399.91	102.33	41.40	6.15	22.27	18.70	11.09	402.85	99.62
14	35.81	10.97	6.42	41.52	7.56	398.59	102.28	41.34	6.09	22.01	18.67	11.01	401.96	99.12
15	35.86	10.99	6.48	41.51	7.51	399.68	102.35	41.54	6.10	22.07	18.73	11.01	402.06	99.45
16	35.81	10.99	6.46	41.55	7.58	399.38	102.40	41.49	6.17	22.12	18.70	11.00	400.99	99.47
17	35.81	11.03	6.50	41.64	7.56	400.16	102.56	41.47	6.06	22.06	18.70	11.09	402.00	99.39
18	35.76	11.01	6.49	41.59	7.51	398.31	102.31	41.34	6.15	22.20	18.63	11.03	402.45	99.35
19	35.84	11.08	6.45	41.38	7.61	400.16	102.36	41.40	6.16	22.10	18.74	10.94	400.50	99.34
20	35.84	11.08	6.48	41.37	7.51	399.11	102.38	41.54	6.12	22.07	18.66	10.99	401.84	99.38
	35.81	11.01	6.43	41.49	7.57	399.50	102.32	41.42	6.14	22.14	18.67	11.04	402.16	99.56

CBACK

SBACK

	CB	NK	SL	Dart	W1	Area	Penphery	Dart	SL	AH	SS	W2	Area	Penphery
1	40.77	8.56	6.43	42.16	7.02	405.10	104.93	41.94	6.22	23.11	18.55	10.48	426.50	100.29
2	40.69	8.58	6.46	42.16	6.99	405.00	104.89	41.76	6.20	22.99	18.65	10.51	427.40	100.21
3	40.72	8.59	6.47	42.18	6.97	405.35	104.93	41.82	6.21	22.88	18.64	10.56	426.26	100.11
4	40.67	8.48	6.50	42.23	6.97	404.56	104.84	41.76	6.18	22.87	18.63	10.49	425.69	99.93
5	40.74	8.47	6.43	42.20	6.97	405.31	104.82	41.96	6.20	22.82	18.56	10.58	427.15	100.12
6	40.77	8.48	6.35	42.12	6.99	403.10	104.71	41.75	6.14	23.05	18.65	10.57	427.36	100.17
7	40.72	8.46	6.41	42.19	6.92	403.69	104.69	41.73	6.20	23.00	18.62	10.53	426.71	100.08
8	40.72	8.50	6.41	42.12	6.97	404.69	104.72	41.57	6.20	22.97	18.58	10.53	426.30	99.85
9	40.72	8.51	6.35	42.14	6.99	404.86	104.72	41.69	6.17	22.94	18.62	10.54	425.76	99.96
10	40.69	8.45	6.43	42.21	7.02	405.00	104.80	41.61	6.15	23.10	18.59	10.55	425.28	99.99
11	40.69	8.56	6.29	42.20	6.99	404.15	104.74	41.55	6.23	22.98	18.61	10.45	424.99	99.82
12	40.69	8.53	6.36	42.15	6.97	403.22	104.70	41.58	6.15	22.95	18.63	10.50	424.96	99.80
13	40.72	8.47	6.56	42.81	7.02	406.25	104.75	41.67	6.24	22.93	18.67	10.54	427.25	100.04
14	40.72	8.50	6.39	42.21	7.02	406.16	104.83	41.67	6.20	23.02	18.65	10.47	425.51	100.02
15	40.69	8.57	6.40	42.12	6.97	404.87	104.76	41.60	6.17	23.03	18.71	10.61	426.00	100.12
16	40.74	8.51	6.38	42.11	7.02	405.42	104.75	41.54	6.22	22.98	18.64	10.52	425.26	99.90
17	40.77	8.46	6.48	42.18	7.05	405.43	104.93	41.65	6.23	22.97	18.64	10.54	425.94	100.05
18	40.77	8.48	6.47	42.17	6.97	405.37	104.85	41.72	6.21	22.87	18.63	10.51	424.43	99.94
19	40.69	8.55	6.44	42.13	6.99	405.24	104.80	41.66	6.24	22.93	18.66	10.52	425.57	100.10
20	40.69	8.45	6.49	42.13	6.97	404.20	104.65	41.61	6.23	22.99	18.67	10.58	425.44	100.09
AVG	40.72	8.51	6.43	42.20	6.99	404.85	104.79	41.69	6.20	22.97	18.63	10.53	425.99	100.03

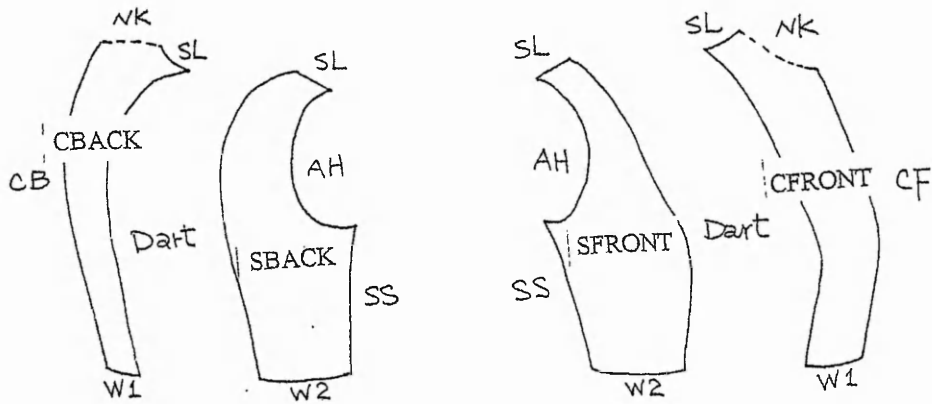
Figure 4.22 The inconsistency of the calico foundation patterns in comparison with their means



CFRONT								SFRONT							
	CF	NK	SL	Dart	W1	Area	Periphery	Dart	SL	AH	SS	W2	Area	Periphery	
1	0.02	-0.12 x	-0.09 x	0.11 x	0.02 x	1.45 x	-0.07 x	0.17 x	0.03	-0.03	-0.03	-0.09 x	1.39 x	0.00	
2	-0.11 x	0.03 x	-0.08 x	0.02	0.14 x	1.26 x	-0.01	-0.17 x	0.11 x	-0.03	0.02	-0.02	-0.38	-0.14 x	
3	0.05 x	0.00	0.02	-0.12 x	0.01	0.83	-0.05	-0.08 x	-0.10 x	0.05	-0.17 x	-0.02	-2.74 x	-0.38 x	
4	-0.08 x	0.02	-0.01	0.07 x	-0.06 x	1.52 x	-0.07 x	-0.02	0.03	-0.16 x	0.02	0.08 x	0.67	-0.11 x	
5	-0.03	0.08 x	-0.03	-0.02	0.01	1.58 x	0.00	-0.04	-0.02	0.04	-0.06 x	0.04	1.10 x	-0.09 x	
6	0.10 x	-0.01	0.03	-0.04 x	-0.01	1.89 x	0.05	0.07 x	0.03 x	-0.07 x	-0.04	0.17 x	0.54	0.05	
7	-0.08 x	0.05 x	-0.01	0.09 x	-0.01	-0.64	0.03	0.03	0.04 x	0.06	0.12 x	-0.16 x	-2.24 x	0.04	
8	-0.03	0.06 x	-0.09 x	0.08 x	0.04 x	-1.64 x	0.06 x	-0.10 x	-0.03 x	0.30 x	0.07	0.00	-0.17	0.19 x	
9	-0.01	-0.02	-0.02	-0.02	-0.04 x	-1.29 x	-0.11 x	0.04	0.15 x	-0.04	0.00	-0.19 x	-0.78	-0.10 x	
10	0.02	0.02	-0.03	-0.05 x	-0.01	-0.32	-0.06	0.08 x	-0.01	0.04	0.00	-0.09 x	-0.12	0.05	
11	0.04 x	0.03 x	0.03 x	-0.02	-0.01	0.56	0.06	0.06 x	0.05 x	-0.03	0.08 x	-0.05 x	-0.90 x	0.07	
12	0.10 x	0.01	-0.11 x	-0.05 x	0.01	0.27	0.18 x	0.01	0.00	0.17 x	0.08 x	0.04	2.00 x	0.26 x	
13	0.12 x	0.05 x	0.11 x	-0.06 x	0.07 x	1.44 x	0.27 x	0.02	-0.08 x	0.18 x	0.00	0.10 x	0.31	-0.17 x	
14	-0.01	0.04 x	0.07 x	-0.01	-0.06 x	-0.72	0.03	0.00	-0.01	0.10 x	-0.10 x	0.01	-0.28	-0.05	
15	-0.03	0.03	0.09 x	-0.02	-0.03 x	0.05	0.02	0.04	0.06 x	0.12 x	-0.04 x	0.02	-0.78 x	0.03	
16	-0.08 x	-0.08 x	-0.18 x	0.02	0.02 x	-1.92 x	-0.30 x	-0.04	-0.03	0.11 x	0.01	0.09 x	1.71 x	0.07	
17	-0.01	-0.02	-0.01	-0.01	-0.01	-1.02	-0.07 x	-0.05 x	-0.08 x	0.13 x	-0.04 x	0.05 x	0.11	-0.04	
18	-0.03	-0.01	0.00	0.03 x	-0.06 x	-0.52	-0.07 x	-0.11 x	0.00	0.15 x	0.04 x	-0.01	-1.64 x	-0.07 x	
19	0.07 x	-0.08 x	-0.01	0.00	-0.01	-0.82	-0.04	0.12 x	0.02	0.03	0.02	0.00	0.24	0.13 x	
20	0.04	-0.01	0.11 x	-0.02	0.02	-2.03 x	0.14 x	0.05	0.01	0.05	0.03	0.02	2.03 x	0.05	

CBACK								SBACK							
	CB	NK	SL	Dart	W1	Area	Periphery	Dart	SL	AH	SS	W2	Area	Periphery	
1	0.04 x	0.26 x	-0.02	-0.05	-0.07 x	-1.55 x	0.16	-0.10 x	0.09 x	0.07 x	0.01	0.02	-0.90 x	0.10 x	
2	-0.06 x	-0.02	-0.09 x	-0.21 x	0.12 x	-5.63 x	-0.50	-0.18 x	0.10 x	0.06 x	-0.03	0.06 x	0.97 x	-0.01	
3	0.02	0.25 x	-0.09 x	-0.14 x	-0.02	0.07	0.02	-0.13 x	0.00	0.02	-0.15 x	0.03	0.94 x	-0.23 x	
4	-0.03 x	0.10 x	-0.08 x	-0.14 x	0.03 x	-3.11 x	-0.13	-0.10 x	-0.09 x	0.02	-0.05 x	0.07 x	0.77 x	-0.15 x	
5	-0.01	-0.05	0.09 x	-0.02	-0.02	1.57 x	-0.01	0.03	-0.01	-0.02	-0.05 x	0.00	0.79 x	-0.05	
6	-0.06 x	0.06	0.00	-0.35 x	0.03 x	-0.09	-0.32	-0.18 x	0.14 x	-0.04	-0.01	0.05 x	0.01	-0.04	
7	-0.03 x	-0.09 x	-0.01	0.04	0.08 x	0.71	-0.01	-0.13 x	0.11 x	0.09 x	0.07 x	-0.02	-0.21	0.12 x	
8	-0.02	-0.11 x	0.04 x	0.02	0.11 x	-0.60	0.03	0.02	-0.03	0.04	0.03	0.04 x	0.37	0.03	
9	-0.01	-0.10 x	0.09 x	-0.13 x	0.00	-0.42	-0.16	0.16 x	0.00	-0.12 x	0.01	0.03	-1.20 x	0.08 x	
10	0.02	0.04	0.03	-0.06	0.05 x	0.87	0.08	0.04	-0.08 x	-0.07 x	0.05 x	-0.14 x	-0.39	-0.19 x	
11	-0.01	-0.13 x	0.09 x	-0.02	0.00	-0.95	-0.06	-0.04	-0.04	0.04	0.04 x	-0.14 x	-1.80 x	-0.15 x	
12	0.04 x	-0.13 x	0.03 x	0.26 x	0.08 x	1.83 x	0.29	0.09	-0.05	-0.04 x	0.05 x	-0.02	0.41 x	0.02	
13	0.04 x	0.11 x	0.02	0.06	-0.02	0.86	0.22	0.03	-0.02	0.02	0.07 x	0.05 x	1.99 x	0.16 x	
14	-0.03 x	-0.01	0.00	0.15 x	0.07 x	-0.23	0.04	0.08	0.09 x	-0.08 x	-0.03	0.02	0.38	0.08	
15	-0.01	0.04	0.04 x	0.13 x	0.03	1.89 x	0.24	0.10	0.05 x	-0.06 x	0.03	-0.06 x	0.21	-0.05	
16	-0.04 x	-0.06	-0.05 x	0.15 x	0.01	2.57 x	0.09	0.03	0.00	-0.05	0.00	0.02	0.09	0.00	
17	-0.01	0.04	0.03	0.11	0.01	1.28 x	0.18	0.04	-0.05	0.08 x	0.00	0.07 x	0.01	0.12 x	
18	-0.01	-0.05	0.03	-0.10	-0.05 x	-0.69	-0.23	0.31 x	-0.10 x	-0.07 x	0.04 x	0.03 x	0.08	0.11 x	
19	0.14 x	-0.14 x	-0.01	0.18 x	-0.02	2.86 x	0.15	-0.22 x	0.01	0.05 x	-0.05 x	-0.01	-1.27 x	-0.07	
20	0.02	-0.09	0.00	0.10	-0.02	-1.09 x	0.00	0.11 x	-0.08 x	-0.01	0.03	0.02	-0.16	0.08	

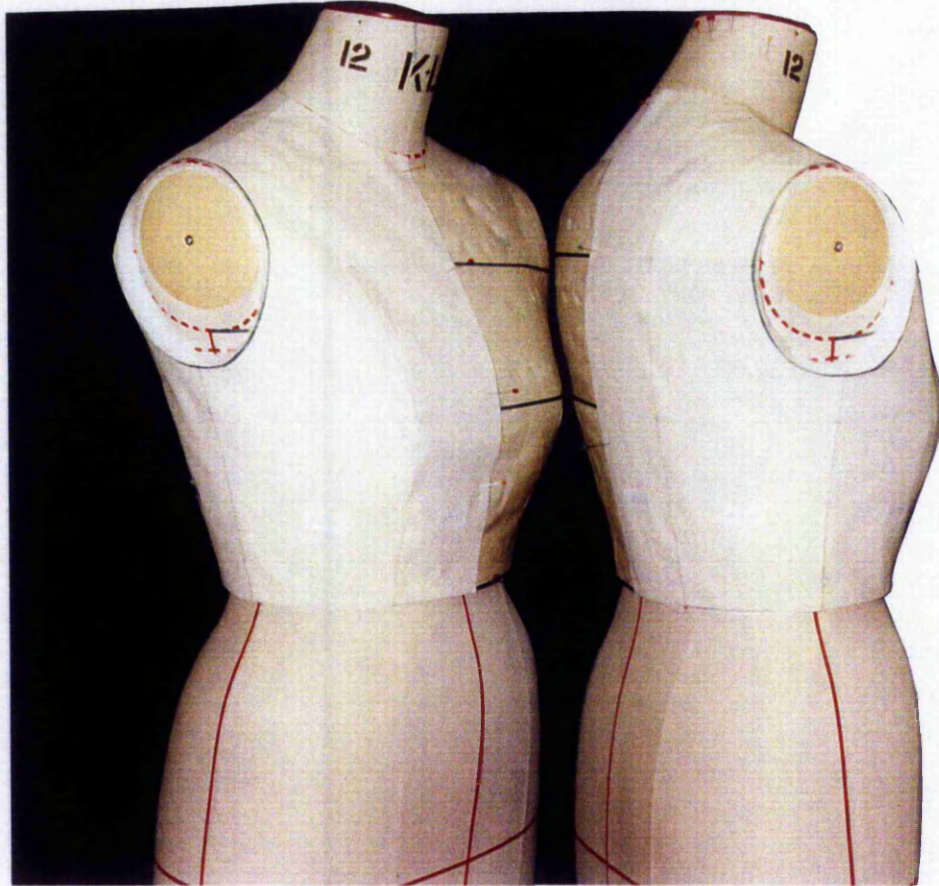
Figure 4.23 The inconsistency of the paper foundation patterns in comparison with their means



CFRONT								SFRONT						
CF	NK	SL	Dart	W1	Area	Periphery		Dart	SL	AH	SS	W2	Area	Periphery
1	-0.02	0.05	0.03	-0.04	0.06	1.33	0.07	-0.13	-0.03	0.18	0.00	0.04	0.74	-0.09
2	0.03	-0.01	-0.05	0.01	0.04	0.25	0.01	-0.07	0.02	0.06	-0.01	-0.01	-1.29	-0.15
3	-0.02	-0.08	-0.05	0.01	0.09	0.33	-0.05	-0.02	0.02	0.05	-0.04	0.07	0.15	-0.07
4	0.00	0.01	-0.02	-0.06	0.14	1.27	0.08	-0.02	0.02	-0.04	-0.04	0.04	-0.50	-0.19
5	0.05	-0.01	-0.04	-0.15	-0.01	-1.33	-0.16	0.08	-0.01	-0.02	-0.06	0.00	-1.42	-0.17
6	0.03	0.02	-0.03	-0.04	0.02	0.00	-0.01	-0.07	0.05	0.05	-0.02	-0.05	-0.04	-0.26
7	0.02	0.03	-0.03	0.03	0.02	0.03	0.02	-0.03	-0.02	-0.02	-0.04	-0.07	0.35	-0.33
8	0.03	-0.02	0.01	0.00	0.01	0.28	0.02	0.21	0.03	-0.09	0.00	-0.10	0.27	-0.12
9	-0.02	0.02	-0.04	-0.05	-0.06	-0.36	-0.17	-0.02	0.04	0.03	-0.02	0.12	2.15	0.03
10	0.12	0.05	0.04	0.02	0.01	0.80	0.00	0.23	0.01	0.08	0.00	0.05	-0.21	2.76
11	-0.02	-0.03	-0.05	-0.01	-0.04	-0.46	-0.23	0.07	-0.03	0.02	0.01	0.02	0.67	-0.07
12	0.05	-0.07	-0.02	0.03	-0.06	-0.36	-0.08	0.08	-0.01	-0.09	0.02	0.10	1.33	-0.04
13	-0.02	0.01	0.02	0.02	-0.01	0.41	0.01	-0.02	0.01	0.07	0.03	0.05	0.69	0.06
14	0.00	-0.04	-0.01	0.03	-0.01	-0.91	-0.04	-0.08	-0.05	-0.13	0.00	-0.03	-0.20	-0.44
15	0.05	-0.02	0.05	0.02	-0.06	0.18	0.03	0.12	-0.04	-0.07	0.06	-0.03	-0.10	-0.11
16	0.00	-0.02	0.03	0.06	0.01	-0.12	0.08	0.07	0.03	-0.02	0.03	-0.04	-1.17	-0.09
17	0.00	0.02	0.07	0.15	-0.01	0.66	0.24	0.05	-0.08	-0.08	0.03	0.05	-0.16	-0.17
18	-0.05	0.00	0.06	0.10	-0.06	-1.19	-0.01	-0.08	0.01	0.06	-0.04	-0.01	0.29	-0.21
19	0.03	0.07	0.02	-0.11	0.04	0.66	0.04	-0.02	0.02	-0.04	0.07	-0.10	-1.66	-0.22
20	0.03	0.07	0.05	-0.12	-0.06	-0.39	0.06	0.12	-0.02	-0.07	-0.01	-0.05	-0.32	-0.18

CBACK							SBACK							
CB	NK	SL	Dart	W1	Area	Periphery		Dart	SL	AH	SS	W2	Area	Periphery
1	0.05	0.05	0.00	-0.04	0.03	0.25	0.14	0.25	0.02	0.14	-0.08	-0.05	0.51	0.26
2	-0.03	0.07	0.03	-0.04	0.00	0.15	0.10	0.07	0.00	0.02	0.02	-0.02	1.41	0.18
3	0.00	0.08	0.04	-0.02	-0.02	0.50	0.14	0.13	0.01	-0.09	0.01	0.03	0.27	0.08
4	-0.05	-0.03	0.07	0.03	-0.02	-0.29	0.05	0.07	-0.02	-0.10	0.00	-0.04	-0.30	-0.10
5	0.02	-0.04	0.00	0.00	-0.02	0.46	0.03	0.27	0.00	-0.15	-0.07	0.05	1.16	0.09
6	0.05	-0.03	-0.08	-0.08	0.00	-1.75	-0.08	0.06	-0.06	0.08	0.02	0.04	1.37	0.14
7	0.00	-0.05	-0.02	-0.01	-0.07	-1.16	-0.10	0.04	0.00	0.03	-0.01	0.00	0.72	0.05
8	0.00	-0.01	-0.02	-0.08	-0.02	-0.16	-0.07	-0.12	0.00	0.00	-0.05	0.00	0.31	-0.18
9	0.00	0.00	-0.08	-0.06	0.00	0.01	-0.07	0.00	-0.03	-0.03	-0.01	0.01	-0.23	-0.07
10	-0.03	-0.06	0.00	0.01	0.03	0.15	0.01	-0.08	-0.05	0.13	-0.04	0.02	-0.71	-0.04
11	-0.03	0.05	-0.14	0.00	0.00	-0.70	-0.05	-0.14	0.03	-0.01	-0.02	0.08	-1.00	-0.21
12	-0.03	0.02	-0.07	0.05	-0.02	-1.63	-0.09	-0.11	-0.05	-0.02	0.00	-0.03	-1.03	-0.23
13	0.00	-0.04	0.13	0.61	0.03	1.40	-0.04	-0.02	0.04	-0.04	0.05	0.01	1.26	0.01
14	0.00	-0.01	-0.04	0.01	0.03	1.31	0.04	-0.02	0.00	0.05	0.02	-0.06	-0.48	-0.01
15	-0.03	0.06	0.07	-0.08	-0.02	0.02	-0.03	-0.09	-0.03	0.06	0.08	0.08	0.01	0.09
16	0.02	0.00	-0.05	-0.09	0.03	0.57	-0.04	-0.15	0.02	0.01	0.01	-0.01	-0.73	-0.13
17	0.05	-0.05	0.05	-0.02	0.06	0.58	0.14	-0.04	0.03	0.00	0.01	0.01	-0.05	0.02
18	0.05	-0.03	0.04	-0.03	-0.02	0.52	0.06	0.03	0.01	-0.10	0.00	-0.02	-1.55	-0.09
19	-0.03	0.04	0.01	-0.07	0.00	0.39	0.01	-0.03	0.04	-0.04	0.03	-0.01	-0.42	0.07
20	-0.03	-0.06	0.06	-0.07	-0.02	-0.65	-0.14	-0.08	0.03	0.02	0.04	0.05	-0.55	0.06

Figure 4.24 The final selected and modified four foundation patterns were assembled using surgical tape



4.6 The Linkage between CDI and AccuMark

Having input the manually toiled foundation patterns into the AccuMark 2D-PDS in order to compare the CDI-3D flattened patterns with the manually toiled patterns, a way of transferring pattern data from CDI to AccuMark needed to be established. The basic configuration in relation to transferring the CDI's pattern data to the AccuMark is shown in Figure 4.25.

This link used the university academic network at the Nottingham Trent University (UK). The PC for processing data onto a floppy disk was a standard Viglen-genie computer of 486/66 MHz processing with 16 Megabyte of RAM and 300 Megabyte of hard disk.

Primarily, the Silicon Graphics UNIX workstation running the CDI software needed to be configured in order to access the university academic network²⁵. This was achieved through the 'EZ' program which is a software utility coming with Silicon Graphics.

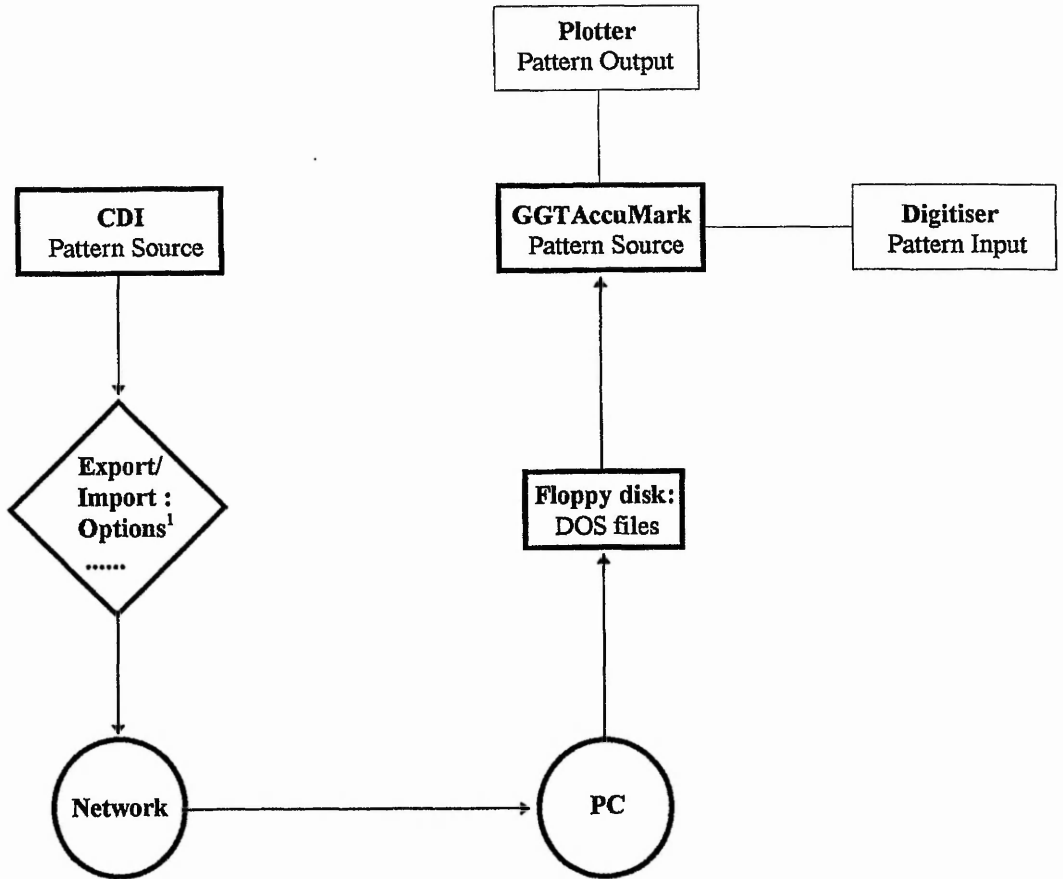
The PC was set up as a standard 'staff' work station on the network. The Silicon Graphics was set up as a 'FTP' (File Transfer Protocol) server. This setup allows communication between the PC and the Silicon Graphics, so that the file data could be transferred between the two systems.

Prior to transferring the CDI-3D flattened pattern to AccuMark, the pattern needs to be saved in an appropriate format so that it can be compatible with the Gerber AccuMark system. This is done via a 'Translator' program²⁶. The 'AccuMark 300' pattern file format was chosen for later comparison because of the participating 2D-PDS. These exported AccuMark 300 pattern files were saved in a directory on the Silicon Graphics computer 'server'.

²⁵ Private talks with Mehdi, a supporting staff in the computer service centre at the Nottingham Trent University, dated Apr. 1997 and May 1998.

²⁶ Two essential parameters are used during the process of pattern file transformation: the 'thin-out cord distance tolerance' and the 'thin-out sharp angle tolerance'. The first tolerance determines how many smooth data points of the pattern are removed from the pattern edges (e.g. the higher the value, the less the points are removed), the second tolerance determines how many sharp points of the pattern edges are kept (i.e. the smaller the tolerance angle, the more sharp points on the edge of the pattern).

Figure 4.25 The basic configuration in relation to transferring 'pattern data' between CDI and GGT AccuMark which is used for this study



CDI

Silicon Graphics - Indigo 2 Extreme
 DesignConcept 3D - 5.2 version, IRIX 5.3
 128 MB memory
 200 Mhz (CPU: MIPS R4400)
 A2 Audio Processor
 Silicon Graphics monitor (GDM-20D11 model)
 Keyboard

Digitiser

NUMONICS, A110S.A model
 digitiser table 170x125 cm
 cursor

AAMA 4.2.5 version

PC Genie pci - p5/66
 486/66 Mhz processing
 16 Megabyte of RAM
 300 Megabyte of hard disk

GGT

HP Vectra __XM2 4/66i
 AccuMark 300 - 7.5 version
 8MB
 66Mhz
 486DX2 processor
 Viglen monitor (CA1726-LE model)
 Keyboard

Plotter

NUMONICS, 8800-1 model (SP-100)
 91.5 cm plot paper width
 HPGL plot type

DXF

¹ They are AccuMark 300, 700, DXF, IGES, and Wavefront file formats.

Having set up this communicating path, the CDI-3D system flattened pattern could be accessed through the PC on the network and saved onto a floppy disk. The pattern file then could be imported into the AccuMark by means of the 'Utilities' program in the 'System Management'. By this means, comparisons of electronically flattened patterns could be made with the digitised manually toiled patterns for the study.

4.7 Summary

It has been previously shown that a key task was the devising of a feasible process which could enable an electronically flattened pattern to be judged by garment pattern making expertise. It was understood that, in order to clarify the deficiencies when applying modern 3D-PDS for garment pattern use, the assessment needed to take place in practice. This was to say that craft techniques were needed prior to making this assessment.

A process has now been established for assessing the electronically flattened patterns, essential requirements were established as stated. They were: creating the sample garment form in a solid type; digitising the created sample garment form data into the selected 3D-PDS, i.e. the CDI-3D; controlling an identical sample garment form in the system through making and verifying the identified control measurements; specifying and controlling the variables which could cause inconsistency for manual garment pattern making; obtaining the foundation pattern²⁷ from the sample garment form and inputting into the selected 2D-PDS, i.e. AccuMark; finally, devising a viable process for comparing the patterns from the CDI and the manual patterns stored in the AccuMark.

The establishment of the 3D solid sample garment form and foundation pattern in the real world, though, still required craft skill, which meant that inconsistency could only be controlled rather than be calculated scientifically; however, it was clear that the three main variables for manual pattern making underlined in section 4.2.2 had been controlled consistently. By conducting an investigation into a fully controlled process of manual garment pattern making, a relatively objective manual pattern stability could be obtained. The consistent foundation pattern which was devised in the real world provides a *standard* to evaluate electronic pattern deficiencies for garment use.

²⁷ It was necessary to acknowledge that these input foundation patterns were still regarded as 'manual' patterns although they existed in electronic data, i.e. the AccuMark pattern data type. The electronic pattern deficiency mainly referred to the electronically flattened patterns.

5 PRACTICAL EXPERIMENTS

5.1 Introduction

Having provided a consistent *standard* pattern in the real world, the validity of the electronically flattened pattern can be evaluated in practice. The crucial feature of the CDI 3D-PDS, i.e. flattening a pattern from 3D to 2D, can be assessed as well as its effectiveness for use specifically in garment patterns.

A garment for a close fitting bodice is a human body-like 3D form with a dual bending curvature (see section 4.5.2, Figure 4.17) for which the bending degrees depend on the bodice construction. Some areas are bent more than the other areas, e.g. blade and bust areas. Darts and seams are often used to produce 'room' for these areas, besides their use for styling the design. These two elements are crucial for evaluation when electronic pattern flattening is examined.

This chapter aims to investigate four issues. First, the electronic pattern flattening process needed to be made clear for use by garment pattern designers. Second, the implications of electronic pattern flattening process were evaluated by means of pattern edge measurements and pattern areas because what appears to be constant garment pattern inaccuracy in the electronic pattern flattening needed to be examined. Third, a comparative study of the electronically and manually flattened pattern was made to demonstrate the measurement accuracy and the shape stability of the pattern. Finally, experiments were undertaken to obtain an accurate bodice pattern using the basic block cutting principles together with the knowledge gained from the previous experiments.

Groups of experiments were conducted and are discussed in four main sections. The first section (i.e. section 5.2) aimed to identify the basic parameters and processes of the systematic pattern flattening used in the CDI 3D-PDS. Two groups of experiments were conducted using cones and spheres because their theoretical measurements and surfaces

could be calculated mathematically. A cone represented a single bending form; a sphere a dual bending form. Darts and seams effects were imposed in experimenting with the spherical surfaces. Both single and dual bending conditions in relation to the flattened results were also investigated.

In the second section (i.e. section 5.3), experiments began with the examination of a basic garment prototype using parameters obtained in the first section. A group of experiments was made to examine pattern accuracy using 1 dart, 2 darts, 1 seam, 2 seams, and 1 dart with 1 seam. Another group of experiments was designed to investigate pattern shape. Two close fitting garment styles were selected to demonstrate the flattened pattern shape stability.

In the third section (i.e. section 5.4), the electronically flattened pattern was compared and contrasted with a manually flattened pattern, by flattening electronically and manually the four foundation patterns from both electronically and manually created sample garment forms (see sections 4.2 and 4.5). Patterns were compared to each other in full size 2D patterns. Later, patterns were assembled to evaluate their 3D garment form.

The final section (i.e. section 5.5) attempted to examine the possibility of obtaining an accurate pattern by identifying and improving the limitations which were caused in the previous three sections of experiments.

5.2 Basic 3D Pattern Flattening in the CDI-3D System

Background to the experiments

The CDI-3D system provided a function (i.e. the 'Regions' program, see section 3.4.2, p.3-65) for flattening any constructed 3D form surface (e.g. sample garment form) to 2D patterns (e.g. the four foundation pattern). The 3D pattern is developed above the 3D form 'Surface' as a 'second skin' (see section 2.2) called a '3D Region' (Figure 5.1). A '3D Region' can be flattened as a '2D Region' (i.e. flattened pattern). It was based mainly on mathematical calculations using finite element analysis. The main idea was to divide a defined 3D pattern surface using numbers of irregular triangular-meshes. The size of the mesh was determined by the area of the 3D surface and its bending degree. By doing this, the pre-defined 3D pattern edge measurements and pattern areas could be calculated and transferred to a 2D pattern mathematically (Figure 5.2).

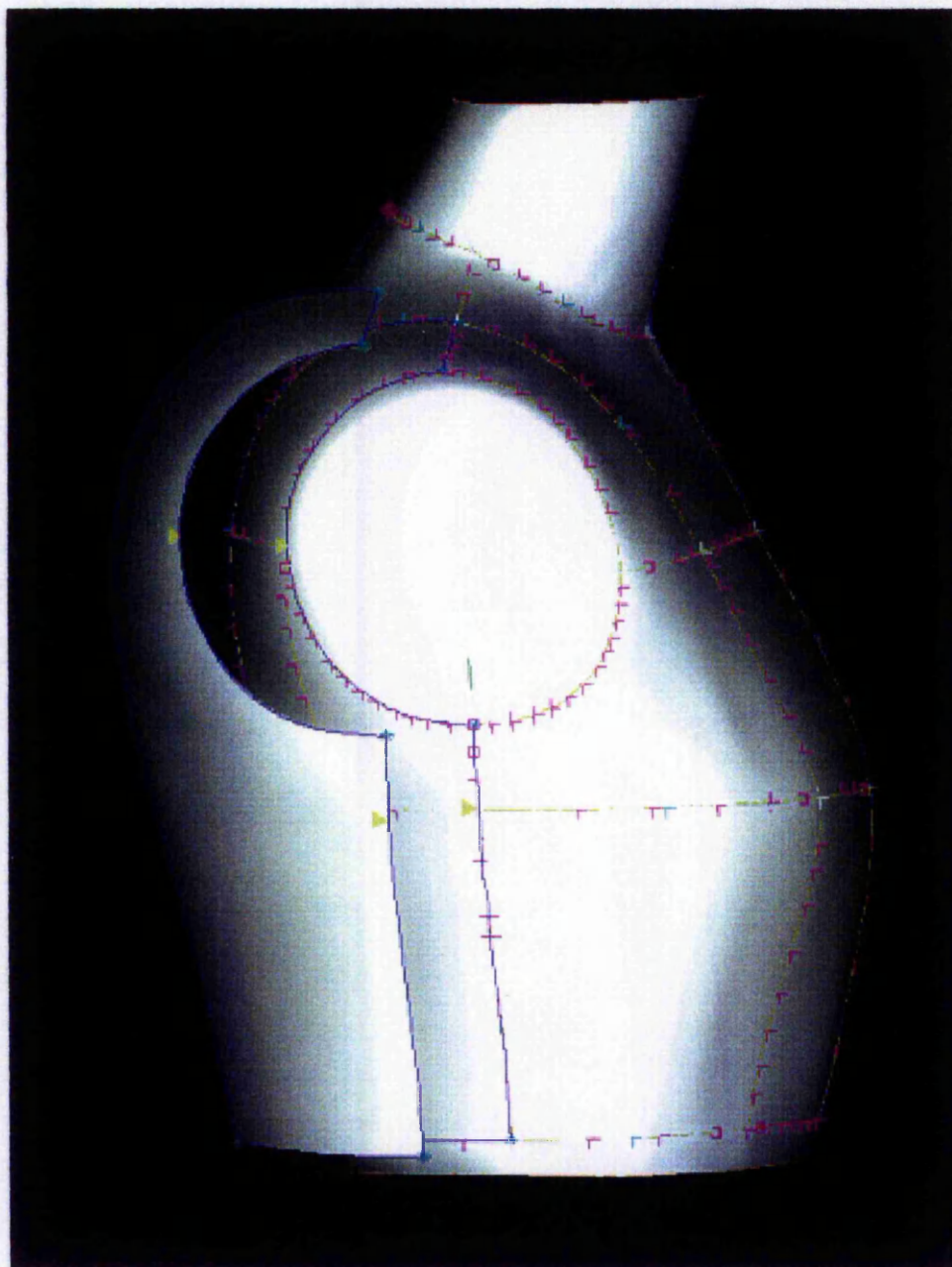
The limitation of using this type of mathematical computation to flatten a 3D form is that pattern edge measurements and pattern areas are not necessarily identical between 3D and 2D patterns (Okabe et al., 1992; Hesley et al., 1988). This is particularly dependent upon the degree of the double curvature¹ and the type of curvature (Hinds et al., 1992).

The bending was deemed to be the major problem to be clarified in the experiments. In order to understand the basic electronic pattern flattening of the CDI-3D system, two basic geometric forms, i.e. cone and sphere, were selected to illustrate this problem. The cone represented one single bending flattening and the sphere represented the dual bending flattening (see section 4.5.2, Figure 4.17). Therefore, the sphere was more likely to be characteristic of a garment form.

This section was designed to identify the related parameters of generating and flattening a basic 3D form in the CDI-3D system.

¹ See section 4.5.2, Figure 4.17.

Figure 5.1 The 'Regions', in the CDI-3D system, represents as the 'second skin'

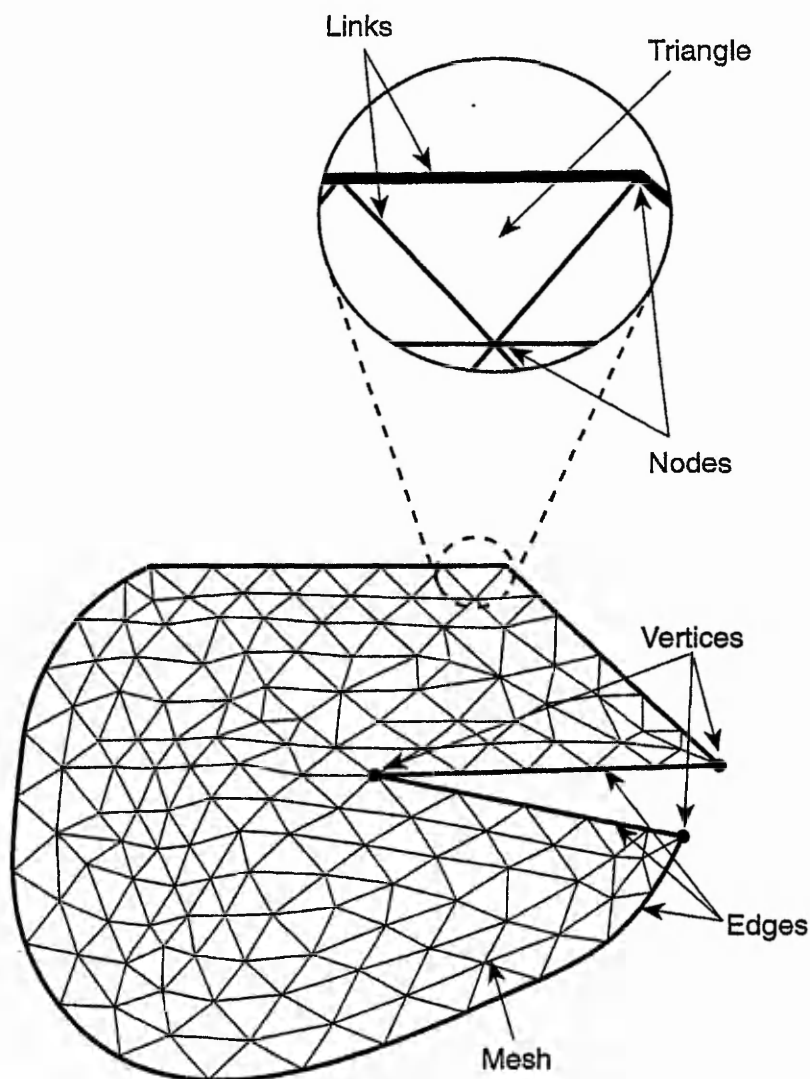


This figure illustrated the created '3D solid garment form' in the virtual world.

The specified form surface (i.e. the 'Region', in purple line) was seen as a 'second skin'.

In this figure, the specified form surface (i.e. the second skin) could be flattened to a 2D pattern with a certain amount of distortion. The flattened pattern was seen as a 'contact-fit pattern' in this study.

Figure 5.2 The illustration of the elements used to flatten a 3D pattern, in the CDI-3D 'Regions' program



This picture is featured in the CDI-3D system manual (CDI, 1995, p.8-7).

Note: The illustration above is the '2D Region' (i.e. the flattened 2D pattern) in the CDI-3D system. By means of these adjustable and countable triangular-meshes, the 3D-PDS can calculate mathematically the conversion of the pattern areas and pattern edge measurements between 3D and 2D; also, pattern shape can be modified manually but is still 'recognised' by the system. For more details, see Appendix 20 (p. A-21).

The experiments in this section used strain analysis which was provided in the system. In order to show clearly the contrasting effects between the tension and the compression during the pattern flattening process, this study selected the 'Absolute'² (Figure 5.3) view to demonstrate the tension and compression of the pattern flattening, i.e. 'blue' indicating the tension and 'red' indicating the compression.

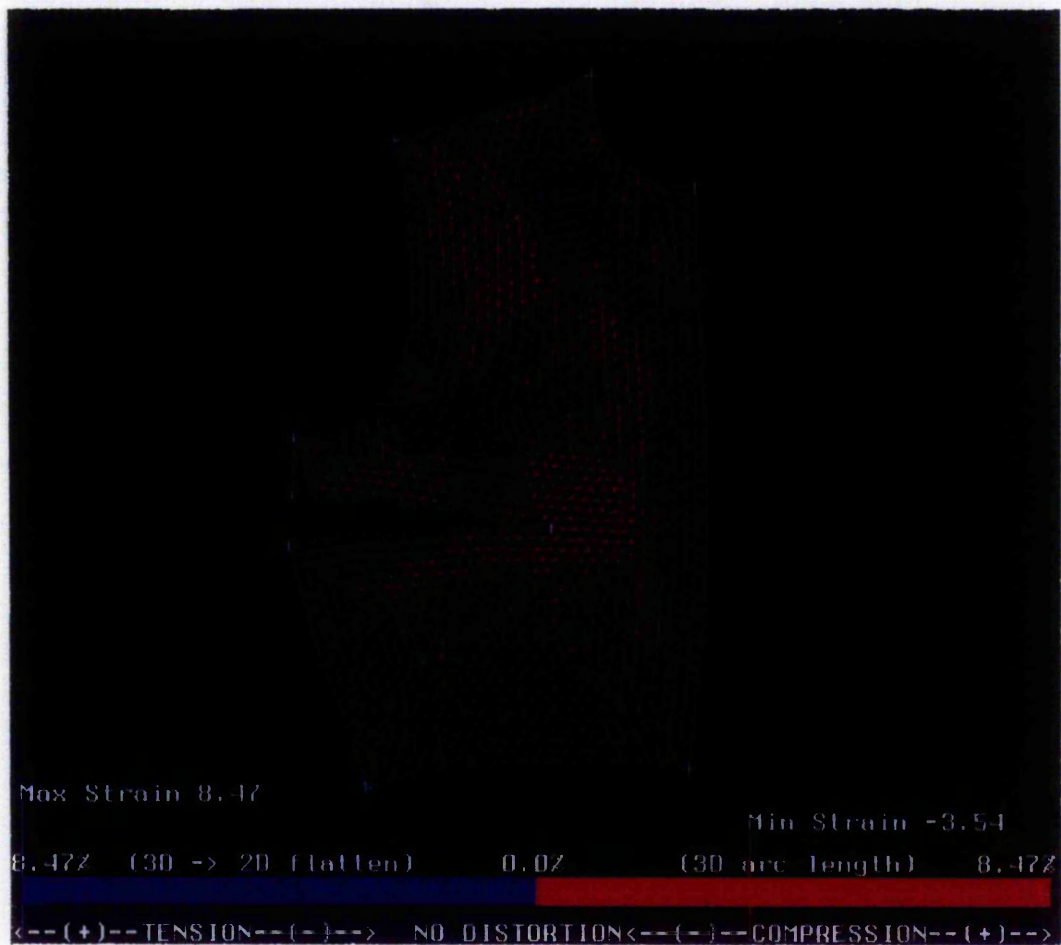
Nine cones were constructed 4, 8, and 12 cm high and with radii of 6, 9, and 12 cm. These proportions were derived from bust sizes from small to large. Three spheres were constructed using 6, 12, and 18 cm. The 6 cm sphere represented a female bust; the 12 cm sphere allowed the comparison of any result with the 12 x 12 cm cone; and the 18 cm sphere was created to examine the relationship of the bust girth.

The first stage was to identify the related parameters of generating and flattening a form with one single bending curvature, i.e. the cone. These parameters were the 'Surface display precision', the 'Mesh link length' (i.e. the mesh size), the 'Mesh node' (in this context, the mesh node point which was selected to begin pattern flattening, see Figure 5.2 and experiment 5.2.1.C), 'iterations' (i.e. the computer counting control for the electronic flattening, see experiment 5.2.1.D), and the single bending condition (for all details, see experiments 5.2.1.A~E). The first four experiments were to understand the basic electronic pattern flattening parameters which were employed by the CDI-3D system. In order to demonstrate clearly the meanings of these parameters, each experiment only explained one single parameter.

The second stage was to experiment with the dual bending form flattening, i.e. the sphere, using one half 'cut', one full 'cut', and two 'cuts', employing the knowledge of parameters proved in the first stage (see experiments 5.2.2.A~C). This was designed to predict the possible variations when the dart and seam effects were used. Finally, experiment 5.2.2.D demonstrated the effect of the depth of spherical curvature which may be applied to the curvature types of the 3D garment pattern.

² There were two colour options, i.e. the 'Absolute' and 'Relative', used in the CDI-3D system. Instead of using blue and red to represent the tension and compression of the flattened patterns, the 'Relative' view used light blue, yellow, to red levels to demonstrate the tension and compression.

Figure 5.3 The representation of the electronic flattening analysis using the 'Absolute' view



The blue meshes, in positive strain (tension), represent the elongated area.
The red meshes, in negative strain (compression), represent the compressed area.

5.2.1 Constructing and Flattening a Cone

In this section, five experiments were conducted as follows.

- Experiment 5.2.1.A The 'Surface display precision' parameter
- Experiment 5.2.1.B The 'Mesh link length' parameter
- Experiment 5.2.1.C The 'Mesh node' parameter
- Experiment 5.2.1.D The 'Iterate' parameter
- Experiment 5.2.1.E The single bending condition

Experiment 5.2.1.A The 'Surface display precision' parameter

In the 3D virtual world, (x, y, z) co-ordinates are used typically for solid geometry. The 'UV Surface' is based on a curvilinear co-ordinate system which exists in but differs from the (x, y, z) co-ordinated system, so that 'curve lines' can be constructed. This enables, for example garment style lines, to be constructed directly on a 3D garment surface.

The 'Surface display precision' controls the precise visualisation of the construction of a 3D form surface. This is determined by the numbers of U and V. The higher the UV numbers, the more planar polygon the 3D form surface. Because the 3D form surface is divided by numbers of planar surfaces, the smooth condition of the 3D form surface can be improved. The UV 'Surface display precision' does not have limits for their values. Notably, the mathematical accuracy of the surface is affected by this display precision only with respect to smoothness.

Purpose

The purpose is to examine the method of generating a cone surface and to assess the relative precision of the constructed cone in the virtual world with respect to UV values.

Processes

In this experiment, the cone with the height of 4 cm and the radius of 12 cm was selected for the demonstration. The basic stages of constructing this cone were as follows:

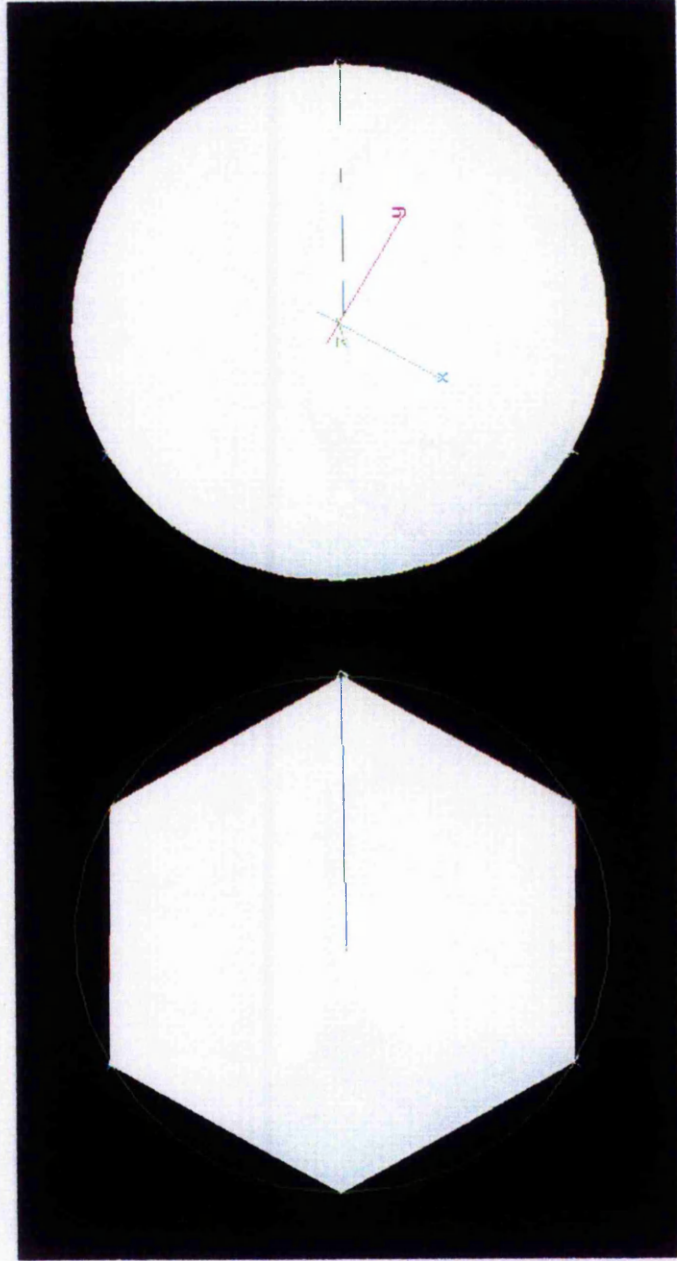
- (1) A circle was constructed with a radius of 12 cm and a point 4 cm above its centre. This apex of the height was connected to one of the points on the constructed circle for the cone.
- (2) A surface was generated for these constructed curves. The cone surface was initially generated with U x V at the lowest 2 x 2 setting of Surface display precision. The bottom of the cone resulted in a 6-sided planar surface (Figure 5.4).
- (3) The U and V 'Surface display precision' was modified by increasing the U x V to 6 x 6, 8 x 8, 10 x 10, 12 x 12, and finally 20 x 20. Further modifications were made using irregular U and V numbers, e.g. 4 x 8, 12 x 2, or 2 x 12. At this stage, the U and V numbers were determined by visual judgement only.

Outcome and analysis

From the experimental results, the UV 'Surface display precision' of '2 x 12', '12 x 12', and '20 x 20' gave visually sufficient precision for the cone (i.e. 4 cm height and 12 cm radius). The higher the UV numbers, the better the surface display precision of the cone. Importantly, each U and V controlled only one single direction of the cone shape. The U represented the horizontal direction of the surface and the V represented the vertical direction of the surface. The surface could also be represented smoothly by changing the V numbers only.

Visually, there was no difference when using the U and V numbers of '2 x 12' and '12 x 12' to display the cone surface, but it was decided to continue to use the '12 x 12' and '20 x 20' (see experiment 5.2.1.B) of U and V in all later cone and sphere experiments. This was because a sphere was a standard dual bending form, hence, the U and V would need to use the same control numbers for each bending direction.

Figure 5.4 Different U V 'Surface Displace Precision' used for a cone [5.2.1.A]



Left: the picture showed the top view of a cone with '2 x 2' U and V surface display precision.

Right: the picture showed the top view of a cone with '12 x 12' U and V surface display precision.

This shows that the higher the UV values, the smoother the circle shape of the cone (the code in the brackets was referred to the related experiment number).

Experiment 5.2.1.B The 'Mesh link length' parameter

The 'mesh link length' (see the 'Links' in Figure 5.2) is the triangular mesh size which is used to recognise and generate a '3D Region' that is the second skin. The medium size cone (i.e. 8 cm height by 12 cm radius) was selected for this experiment because of its similarity to the medium bust size.

Purpose

The purpose is to evaluate the suitable mesh link length for creating and flattening a 'second skin' for one particular size of cone in order that it could be applied later to create a sphere and a garment form.

Processes

The method of constructing this cone (i.e. 8 cm height and 12 cm radius) was the same as the previous experiment. The basic selections of the 'Mesh link length' were made using units of 5, 7.5, and 10 where value depends on the 'default working environment'³. There are no limits for the Mesh link length. Its selection was usually determined comparatively to the size of the defined 3D Region. The processes were as follows.

- (1) The 3D Region was generated on the cone surface. This electronic pattern generated 'second skin' was held above the constructed surface.
- (2) The 3D Region was then flattened to the 2D Region. The '12 x 12', and '20 x 20' U and V numbers were used. The system warned of the overhigh U and V Surface display precision of '20 x 20' for the constructed cone, and suggested approximately '12 x 12' which were hence applied for the rest of the cone and sphere experiments.
- (3) When flattening, the system *automatically* picked up the 'gravity point'⁴ of the specified 3D Region (i.e. 3D pattern area). Manual selection of the beginning flattening point was also used.

³ This refers to the unit option which is used to flatten the pattern. 8 unit options are available in the CDI-3D system, i.e. mm, cm, metre, kilometre, inch, feet, yard, and miles. This study used 'mm'.

⁴ For details, see experiment 5.2.1.C, pp. 5-14~18.

(4) (The 'Iterate' program was used to develop the Region meshes which consisted of 3 stages: 'Layer', 'Total', and 'Final' (for details, see experiment 5.2.1.D). They were used to control the computer counting process for the electronic flattening. 10, 25 and 100 were suggested because they provided a reasonable flattening time and flattened pattern shape (this is discussed in experiment 5.2.1.D).

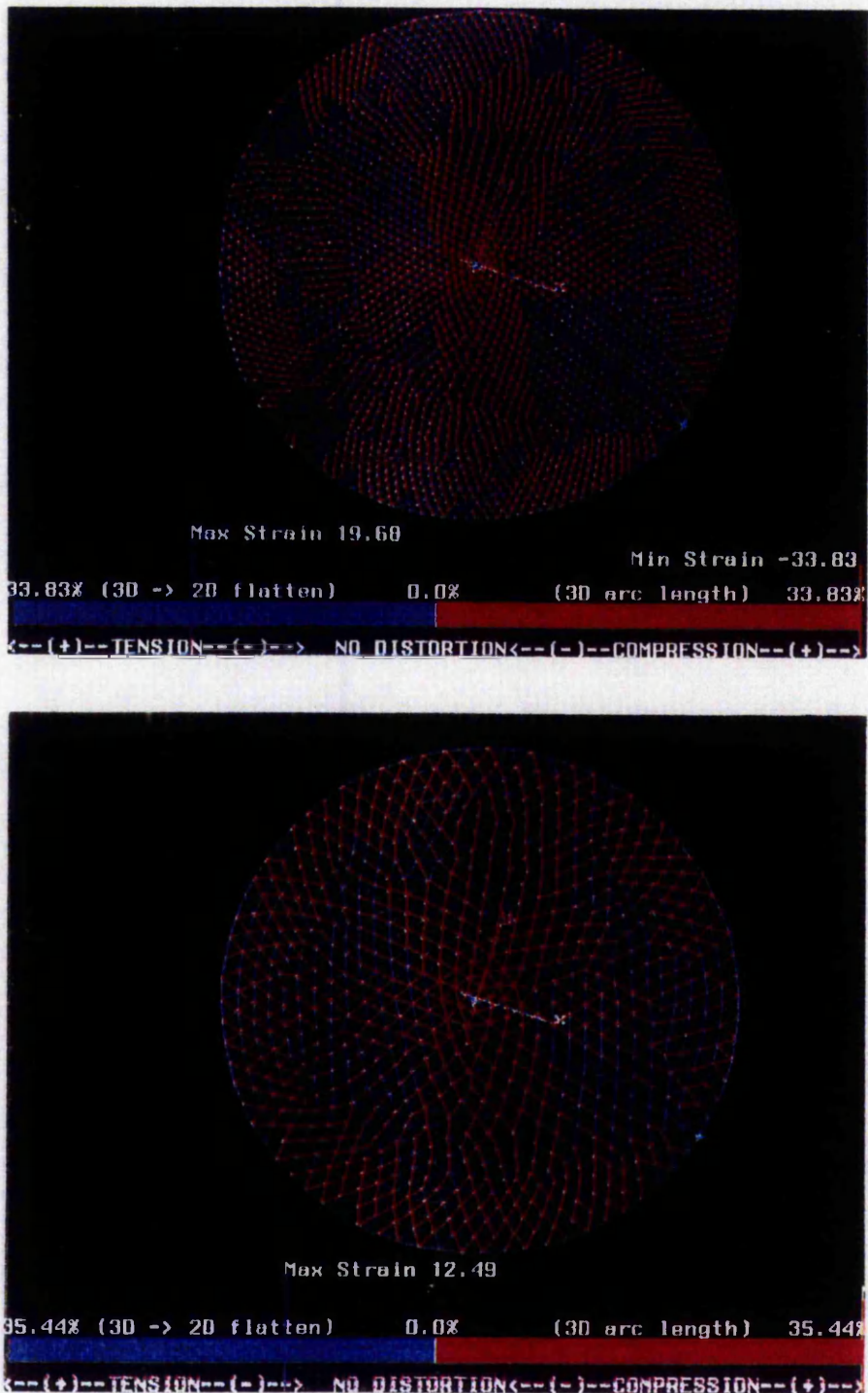
Outcome and analysis

Figure 5.5 showed the 'Mesh link length' using respectively 5 and 10. It was found that the smaller the mesh link length selected, the higher the range of tension (i.e. maximum strain) and compression (i.e. minimum strain) was caused. It was also noticed that both tension and compression were distributed less symmetrically in the cone when it was flattened using a Mesh link length of 5 rather than 10. This was because the smaller mesh size, the more the mesh numbers and computer calculation were required. Thus, the flattened pattern area could be obtained which was closer to the related 3D pattern area; however, the pattern edge measurements was changed correspondingly.

It appeared that to calculate the smaller mesh link lengths, the computer used more time and more computer memory and, so was more prone to crash. However, there was only a very small difference amongst the three flattened 2D Regions.

Therefore, an 'average' value was necessary for practical application. This study chose 'mm' as a default working environment for its appropriate measurement unit for use in a garment condition. From this experimental experience, it was decided that for basic garment pattern use, the mesh link length of 7.5 mm was seen as sufficient. This mesh link length was used for the rest of the experiments in order to control consistency when making comparisons.

Figure 5.5 Different 'Mesh link length' used for flattening a cone [5.2.1.B]



Top: the cone (8cm height x 12 cm radius) was flattened using the mesh link length of 5.
 Bottom: the cone (8cm height x 12 cm radius) was flattened using the mesh link length of 10.
 This shows that the larger the link length, the lower the range of tension (i.e. maximum strain) and compression (i.e. minimum strain) is caused.

Experiment 5.2.1.C The 'Mesh node' parameter

The 'Mesh node', here, is the node point (see Figure 5.1) selected to begin flattening which is the 'gravity point' of the defined 3D Region (i.e. the defined 3D pattern surface). The 'gravity point' is a particular mesh node on a triangular-mesh-generated 3D pattern. The 3D electronic flattening is programmed to reduce distortion to a minimum by selecting this point to begin flattening. This is generally done by the software, itself, but a manual option is also available.

Purpose

The purpose is to find whether the flattened cone pattern shape would be different if the flattening point started from the non-gravity point of the pattern. If the results proved to be inconsistent, then it would be necessary to examine whether this type of flattening could satisfactorily produce a pattern for garment use.

Processes

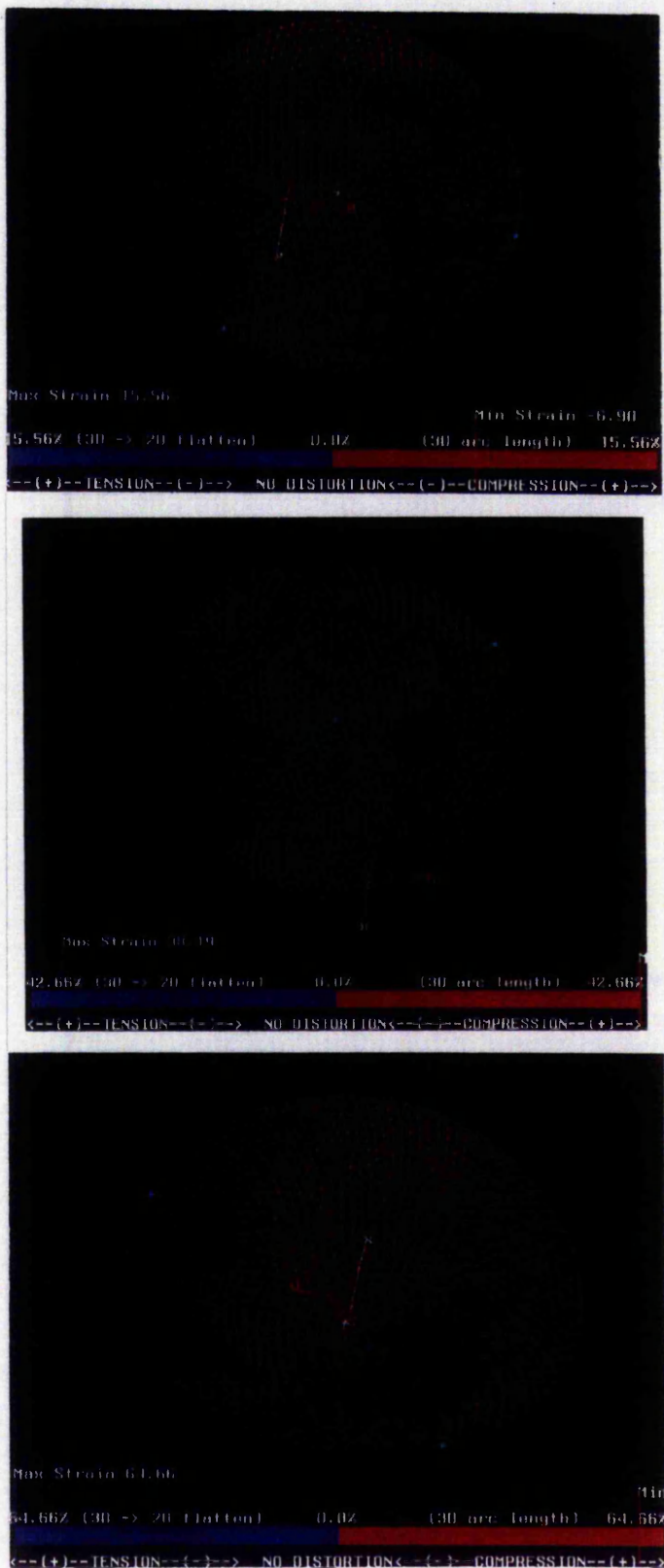
From the experiments, it was decided to use the three cones constructed using '4 x 12', '8 x 12', and '12 x 12' height and radius. Each of these three cones was flattened with and without a cut. The basic flattening process for the cone without a cut was the same as the previous processes in experiment 5.2.1.B. For the cone with a cut, the flattening processes were as follows.

- (1) The 3D Regions were generated by selecting the circle and the slope length of the cone to develop meshes.
- (2) Two experiments were undertaken. The first flattened the 3D Region using the gravity point of the specified 3D Region set by the program, and the second flattened the 3D Region by selecting the apex point of the cone.

Outcome and analysis

First, when the 3 cones without cuts were flattened from the apex point of the cone, they were more distorted than when they were flattened from the gravity point (Figure 5.6).

Figure 5.6 The 3 cones which were flattened from the apex points of the cones [5.2.1.C]



Top: the cone (4 cm height x 12 cm radius) | The distortion of the three cones increases with
 Middle: the cone (8 cm height and 12 cm radius) | increase in the height to the radius.
 Bottom: the cone (12 cm height and 12 cm radius)

However, this did not necessarily prove that flattening from the gravity point of a cone would be better than flattening from other points⁵ of the specified 3D Region.

Second, the tension and compression caused for the three cones with cuts were less than the three cones without cuts. Importantly, the cones with cuts flattened from the apex point showed that the tension and the compression were gathered along the two sides of the cut lines, whereas the cone flattened from the gravity point showed that the tension and compression were balanced evenly at two sides of the flattened patterns (Figure 5.7).

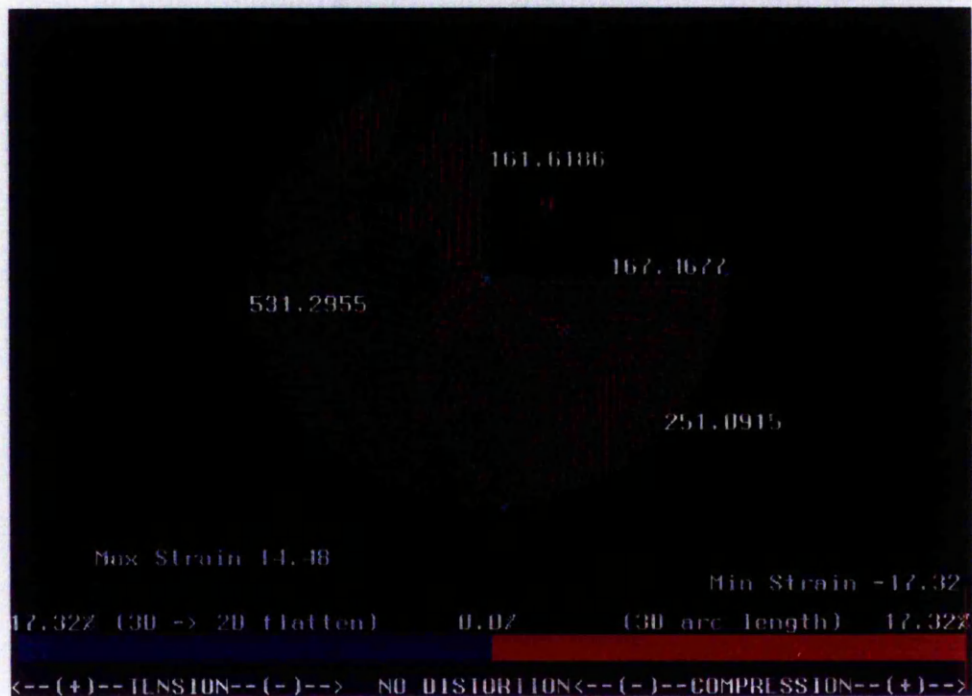
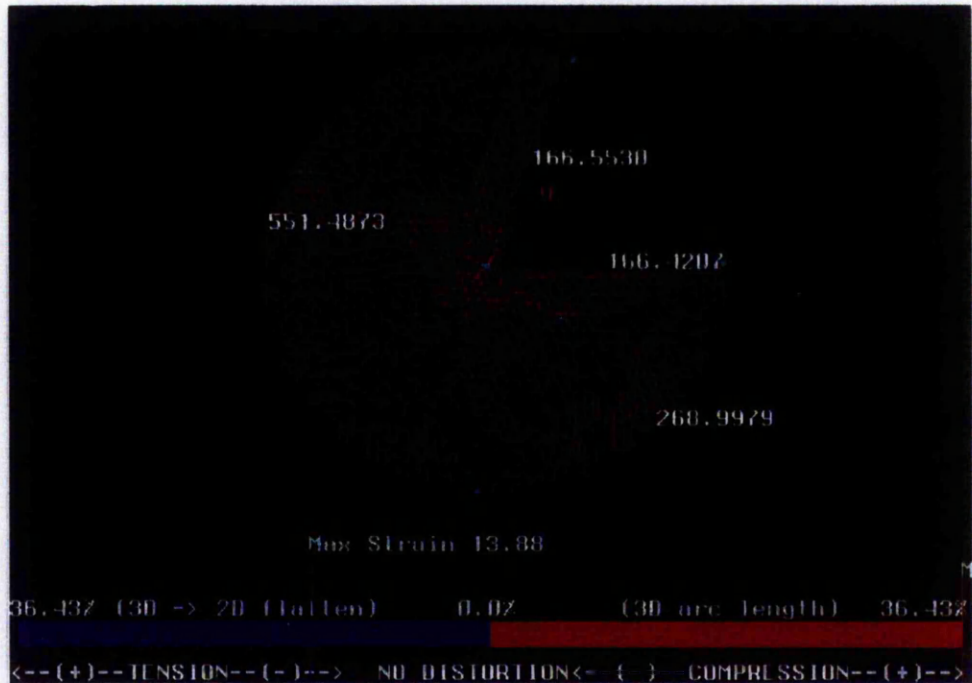
Third, the 2D Regions of the three cones with cuts when flattened from the gravity point of the 3D Regions, appeared to cut wider than when flattened from the apex points (Figure 5.8). At this stage, flattening from the gravity point of the 3D Region to a flattened cone pattern obtained more comparable pattern edge measurements and areas to those of the 3D cone. However, it is also generally understood that, in manual cutting, a cone surface that is flattened with a full cut (i.e. a cut to the apex point of the cone) would result in a consistent sector of a circle. In Figure 5.8, the cone was flattened three times using the same parameters, and the results obtained were identically asymmetrical when overlapping at the centre point of the flattened sectors of the circles.

Finally, it was very important to observe that, when flattened from either point, the perimeter of the cone showed distortions. From the illustrations in Figures 5.7 and 5.8, the flattened pattern shapes were unstable if the flattening point of the defined 3D Regions were selected differently.

⁵ There would be other points, but it would seem that the apex point of the cone would be the most significant.

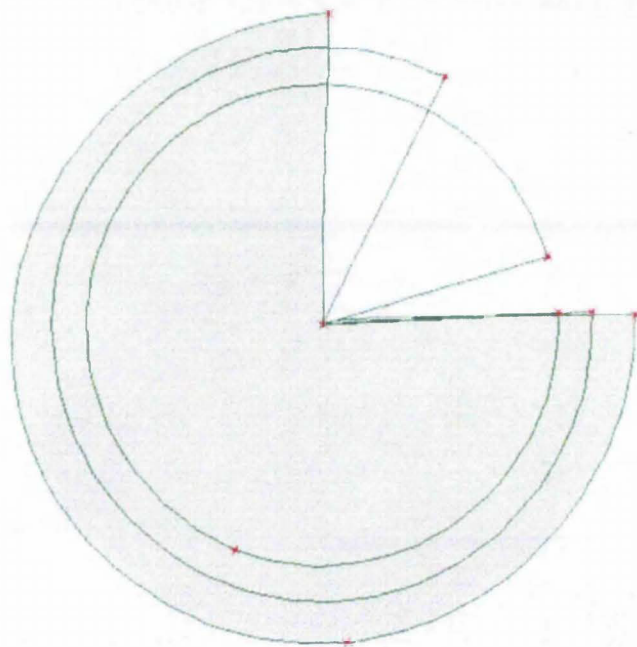
Figure 5.7

The two cones which were flattened by selecting different 'mesh node' starting points for flattening [5.2.1.C]

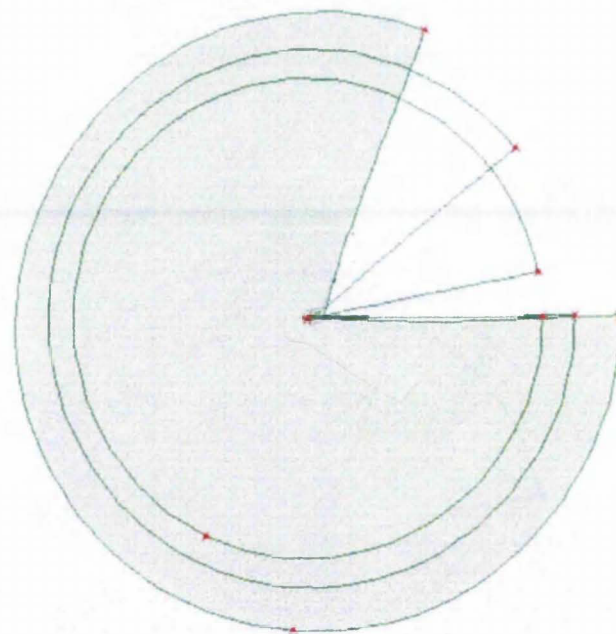


Top: the cone was flattened from the apex point, this was selected manually.
Bottom: the cone was flattened from the gravity point, this was automatically selected by the system.
The top cone was with slightly lower tension but much higher compression than the bottom cone.

Figure 5.8 The three cones which were flattened by selecting different 'mesh node' starting points for flattening [5.2.1.C]



Left: the three cones flattened from the gravity point of the cone surfaces.



Right: the three cone flattened from the apex points of the cone surfaces.

Experiment 5.2.1.D The 'Iterate' parameter

The 'Iterate' program is a count control of the flattening process. In the flattening process, the system primarily picked up the gravity point of the defined 3D pattern (see experiment 5.2.1.B), then the control of the flattening counts could be set individually. This count control basically consisted of three stages. The 'Layer' stage is intended to add new mesh layers; the 'Total' stage is intended to distribute and balance the existing mesh layers; the 'Final' stage shows that software settled the meshes by minimising the tension and compression through meshes. 'Iterations' are the number of times an algorithm processes data. In many cases, the more the iterations, the longer the time, but the better results are obtained (CDI, 1995, pp.8-62~63). Of these three stages for flattening counts, the 'Total' stage appeared to control the main process of the iteration because it controlled the mesh distribution and balance.

Purpose

The purpose is to evaluate how the 'Total' count control actually affected the flattened pattern. The results may provide a reference for use in garment pattern flattening.

Process

This experiment was mainly based upon the experiment 5.2.1.B, but the only selected cone was 8 cm high with a radius of 12 cm; the link length was set as 7.5; the 'Total' count control was modified as 100, instead of the original 25.

Outcome and analysis

For the cone without a cut, the 100 'Total' count control obtained a pattern area and edge measurements closer to 3D than that of 25, but for the cone with a cut, both flattened patterns were almost identical. However, it took more than twice the time to complete.

Setting the counting control at 100 for flattening did not significantly change the flattened pattern condition, hence, in consideration of the time factor, the 'Total' count control of 25 was set for the rest of the experiments. This was seen as sufficient for use in flattening garment patterns.

Experiment 5.2.1.E The single bending condition

Nine cones were constructed using 3 different heights in conjunction with 3 different radii (i.e. the heights of 4, 8, 12 cm and the radii of 6, 9, 12 cm). In turn, there were 9 different degrees of single bending types of cones to be examined.

Purpose

The purpose is to examine the variations of the electronic pattern when flattening different bending cone types (i.e. by changing the ratio of the height to the radius of the cone).

Processes

The experiments were designed to use the 9 cones with and without cuts. This meant that a total of 18 different cones were used in the experiments.

(1) The relative parameters were set up as follows: the U and V 'Surface display precision' of '12 x 12'; the 'Mesh link length' of 7.5; for the cones without cuts, the selection for the flattening was the circle only (see experiment 5.2.2.B); the 'Iterate' count control was set to 'Layer' of 10, 'Total' of 25, and 'Final' of 100.

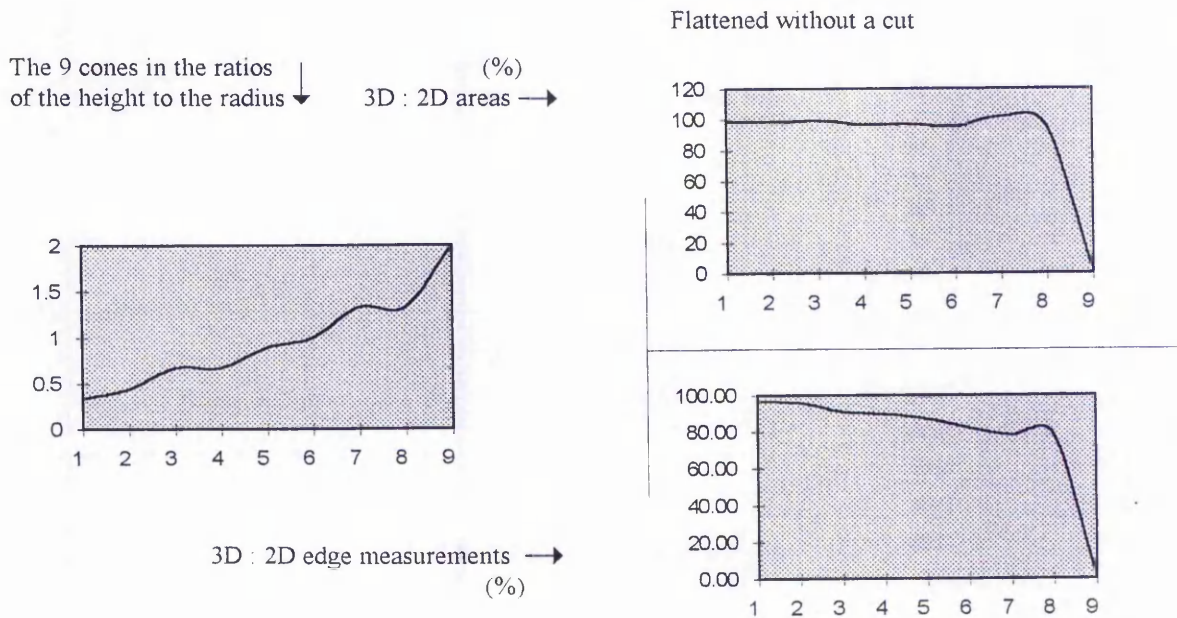
(2) The flattening processes were the same as experiments 5.2.1.B~C: the 9 cones without cuts used the same processes as experiment 5.2.2.B (p.5-25); the other 9 cones with cuts used the same processes as experiment 5.2.2.C (p.5-28).

Outcome and analysis

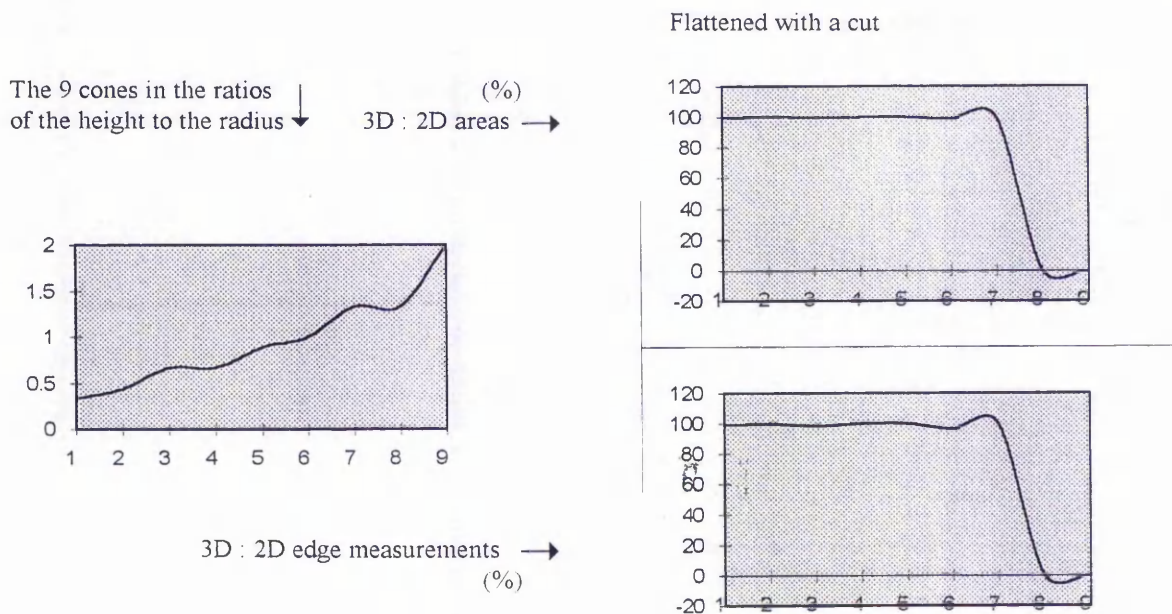
From the flattened results (Appendix 21), it was found that, in the 9 cones without cuts, the pattern edge measurements gradually changed in the ratio of the height to the radius. The greater the ratio, the less the consistency between 3D and 2D (Figure 5.9).

In the 9 cones with cuts, the inconsistency between 3D and 2D was reduced significantly. The graphic illustration in Figure 5.8 proved this statement. The last two ratios of the cones with cuts could not be flattened by the system because of the severe cone bending types.

Figure 5.9 The graphic illustration for the 9 different ratios of the height to the radius, they were flattened respectively without and with a cut



The higher the ratio of the height to the radius of the cone, the less consistency the pattern edge measurements between 3D and 2D (see right bottom picture). In addition, The cone, of 12 cm height and 6 cm radius, could not be flattened because of its severe cone type.



The pattern areas and edge measurements between the 3D and 2D patterns were reasonably consistent amongst the 9 cone types. The two cones, respectively of 12 cm height by 9 cm radius and 12 cm height by 6 cm radius, could not be flattened by the system because of their severe cone types.

5.2.2 Constructing and Flattening a Sphere

In this section, three experiments were conducted as follows:

- Experiment 5.2.2.A The dual bending form with a half cut
- Experiment 5.2.2.B The dual bending form with a full cut
- Experiment 5.2.2.C The dual bending form with two cuts
- Experiment 5.2.2.D The dual bending condition

Experiment 5.2.2.A The dual bending form with a half cut

Dual bending refers to a 3D form with its surface curvature bending in two directions at right angles to each other. A typical example of this kind of form is the sphere. The half cut, in this context, refers to a 'quarter arch' along the half sphere surface.

The experiments in this section used the previous parameters (see the first step of the experiment 5.2.1.E). Three spheres were constructed using radii of 6, 12, and 18 cm, but only a half sphere was used in the experiments. Each sphere was flattened using three different sphere height to radius ratios: 1/3, 2/3, and 1. This section only focused on the half sphere with a cutting line.

Purpose

The purpose is to evaluate pattern shape variations when only a single half cut was used to flatten a spherical surface.

Processes

The basic processes of creating and generating a sphere were as follows:

- (1) A sphere was constructed using only a radius. Initially, the sphere was built up with multiple planar surfaces. To smooth the surface, the UV 'Surface display precision' was modified to '12 x 12'.

- (2) A circle was constructed, and then converted to a curve type which could be attached to the spherical surface. This converted circle could be seen as a slice cut off the spherical surface.
- (3) Another curve was constructed using the same method. This curve was the 'cutting line' on the sphere.
- (4) The flattening process was the same as in experiment 5.2.1.C. An important process was to match the linking points between curve and curve. Without checking this process, the software could crash. The flattened patterns are illustrated in Figure 5.10.

Outcome and analysis

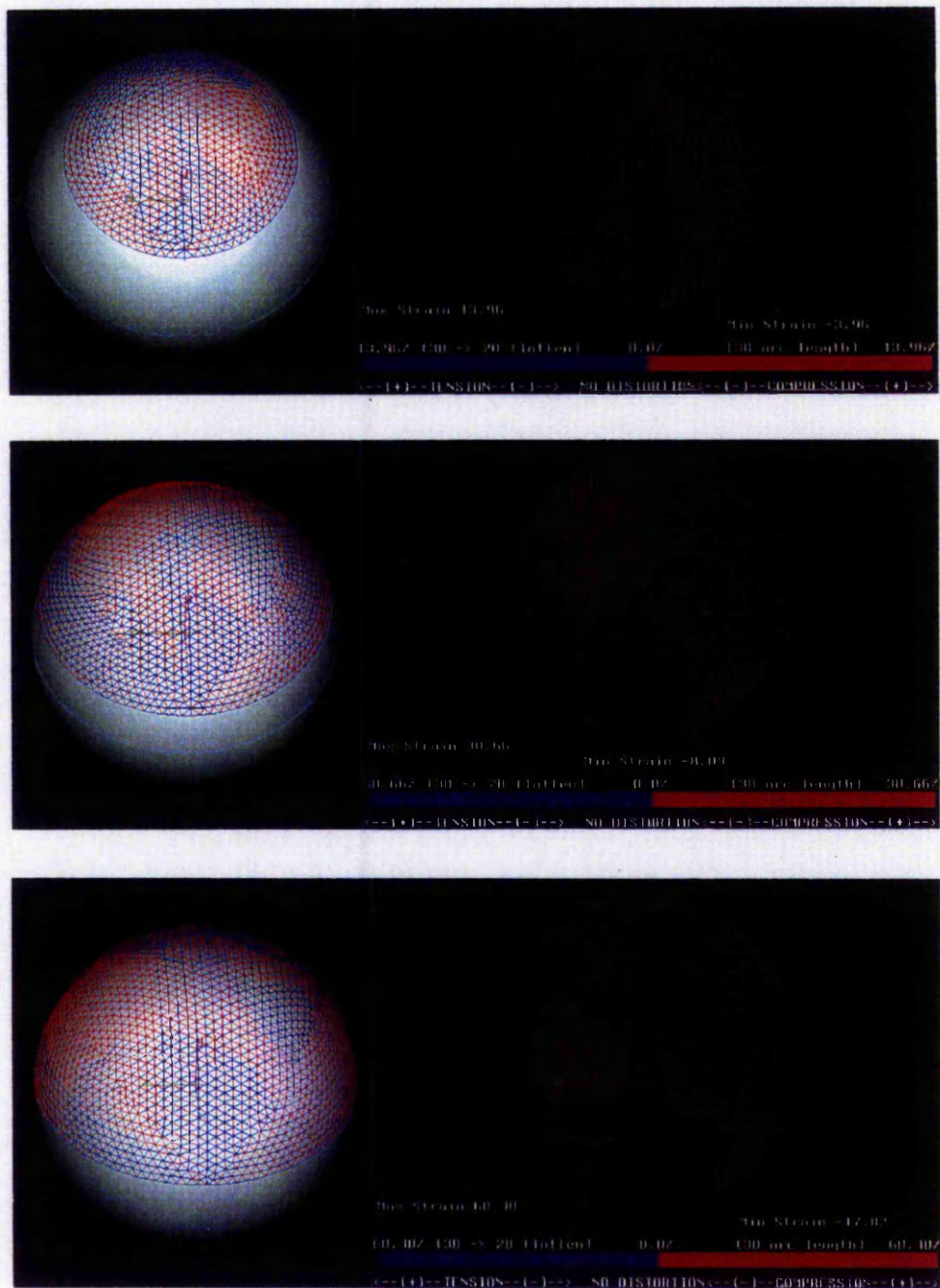
From the experimental results, three main groups of edge measurements variations were seen as approximately regular and could be identified using the different ratio groups.

The first group was about 5-7.5 % enlarged when flattened to 2D Regions. In the second group, this enlargement increased to 12-15 %, and finally, the third group were even enlarged to 20-25 % (Appendix 22).

The pattern areas between 3D and 2D also showed another type of regular change; their variations were less than the pattern edge measurements. Within the same ratio group, the larger the surface constructed, the more inconsistent the pattern areas between 3D and 2D.

Finally, the cutting length on the flattened pattern consisted of two different lengths; both pattern shapes were distorted and the lengths inconsistent when compared with each other. In manual cutting, a sphere that is flattened with a cut would produce two consistent cut lengths. This may imply that, although electronic pattern flattening is always consistent (see experiment 5.2.1.E, 'Outcome and analysis'), the electronically flattened patterns still need to be validated, i.e. the pattern checking process is necessary.

Figure 5.10 The flattening of three different spherical surfaces from the sphere of 12 cm radius [5.2.2.A]



Top: the spherical surface at the level of 4 cm height and 9 cm *bottom radius*.
 Middle: the spherical surface at the level of 8 cm height and 11.3 cm *bottom radius*.
 Bottom: the spherical surface at the level of 12 cm height and 12 cm *bottom radius*.
 This shows the higher ratio of the height to the radius of the spherical surface, the higher the distortion of the flattened spherical pattern.

Experiment 5.2.2.B The dual bending form with one full cut

The 'full cut' refers to an arch (e.g. a seam) along the major distance of the half sphere; this arch divided the half sphere into two quarters of the whole sphere (Figure 5.11).

Purpose

The purpose is to assess the flattening when one direction of the major bending curvature on the half sphere was cut off. Also, to compare with the last experiment 5.2.2.A.

Process

This experiment adapted the 9 types of different spherical surfaces which constructed in last experiment 5.2.2.A. The rest of processes were as follows:

A cut was constructed at the major distance of each of the spherical surfaces. Then, all the connecting points which specified the surfaces needed to be matched in order that, later, flattening could be held. The rest of the flattening processes was the same as stated in experiment 5.2.1.B.

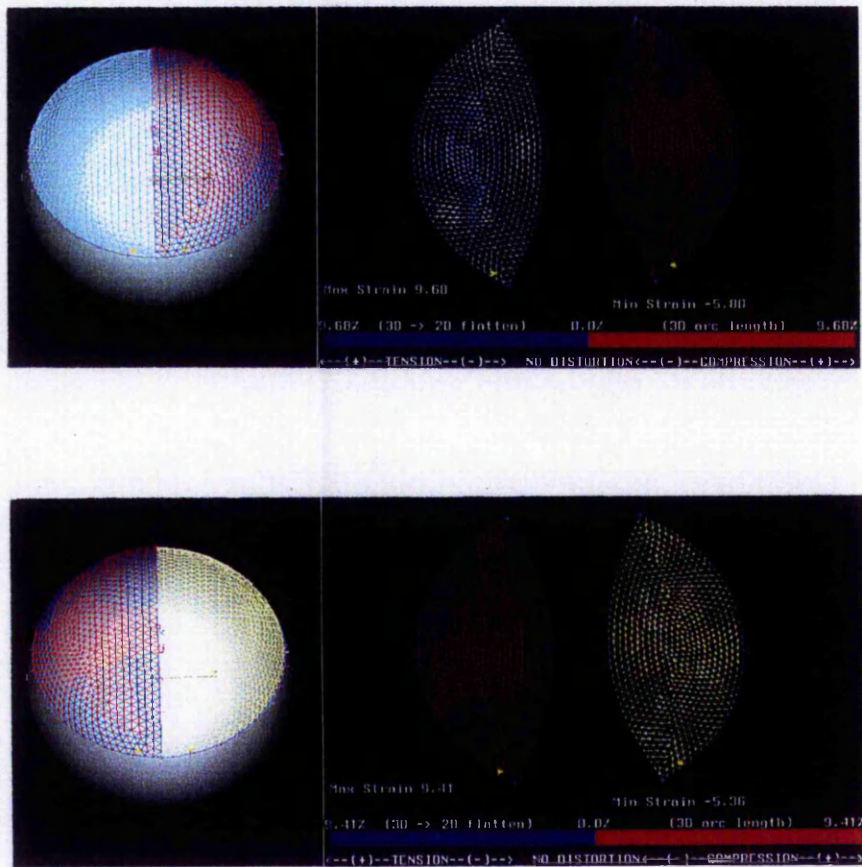
Outcome and analysis

The variations of the flattened spherical areas (Figure 5.12; Appendix 23) were less consistent between 3D and 2D when compared with the cone (see Figure 5.9).

The variations of the flattened spherical surfaces became inconsistent gradually from small to large ratio of the height in relation to the bottom radius. The variations of the cut lengths also had a similar distortion. The greatest distortion was approximately 10 % in the half spherical surface with a radius of 18 cm.

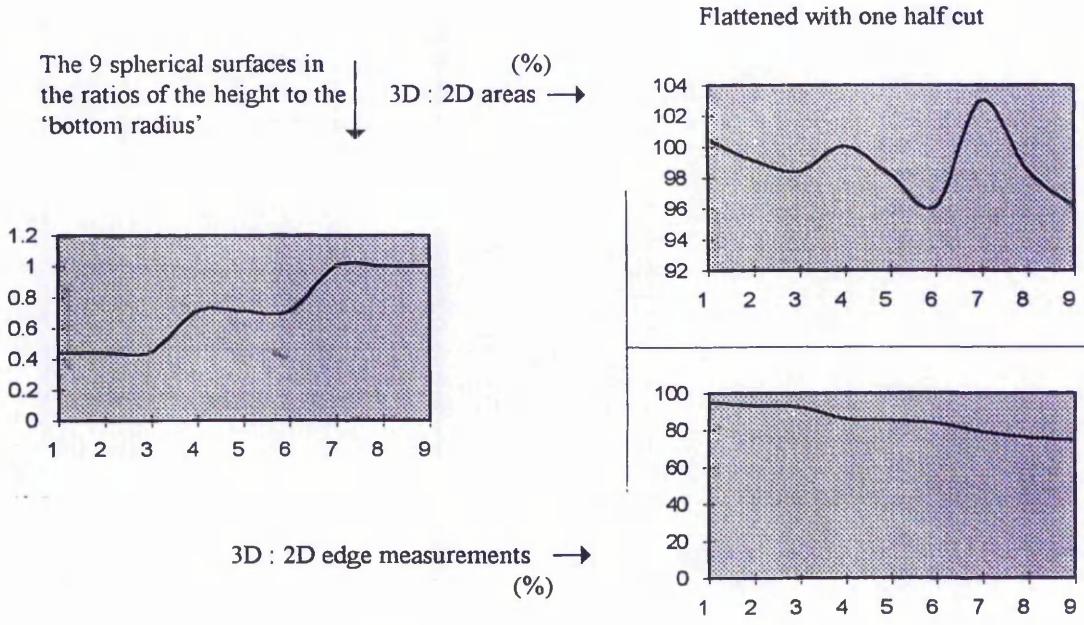
Figure 5.12 illustrates that the distortion of the spherical surfaces was more significant than that of the cone surfaces. Also, the distortion on the flattened spherical surfaces was greater when it had a half cut than when it had a full cut. This may be seen as the different distortions caused by a dart and a seam.

Figure 5.11 The spherical surface flattened by one full length of cut [5.2.2.B]

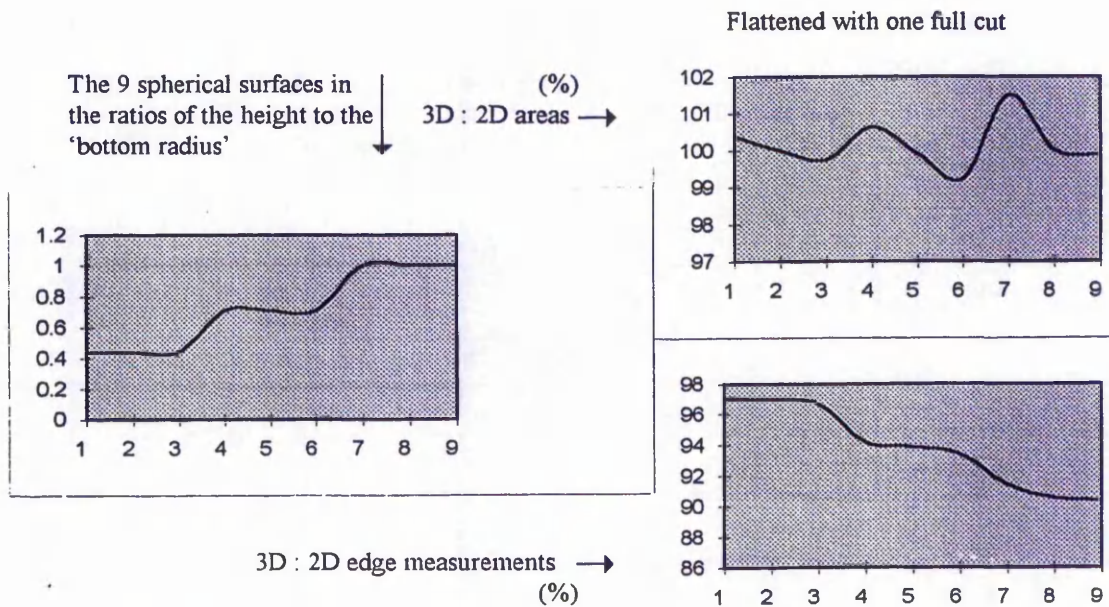


The two almost identical 3D spherical surface were flattened to 2D patterns with almost the same tension and compression caused. The yellow keymarks were used to show the relationship between 3D and 2D spherical patterns.

Figure 5.12 Graphic illustration for 9 spherical surfaces in different height to 'bottom radius' flattened with a half and a cut respectively



Three levels of the spherical surfaces were observed (left). With 1 half cut, in the case of obtaining more consistent pattern areas (right top), the higher the ratio of the height to the bottom radius of the spherical surfaces, the less consistent were the pattern edge measurements between 3D and 2D (right bottom).



With 1 full cut, the flattening results were similar to the results showed above; however, the distortion of the pattern edge measurements between 3D and 2D was reduced from 25 % (right bottom in the upper diagram,) to 10 % (right bottom).

Experiment 5.2.2.C The dual bending form with two cuts

Having experimented with cutting the half sphere into two quarters of the whole sphere using a half arch along the half spherical surface (see experiment 5.2.2.A), it was decided to add one more cut (i.e. the second half cut) which vertically intersected with the first half cut.

Purpose

The purpose is to evaluate the cutting direction in relation to the bending direction and the cut numbers.

Processes

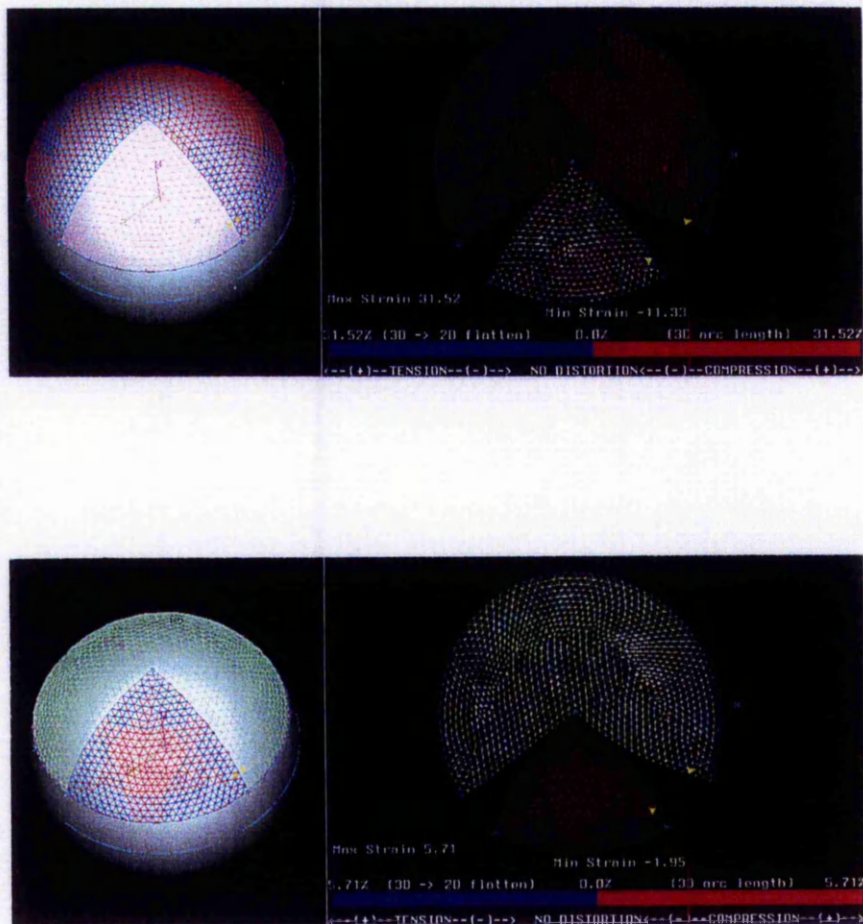
This experiment was a slightly modified adaptation of the previous experiments 5.2.2.A and 5.2.2.B. The basic processes were as follows:

- (1) The curve of the major cut length on the 3D spherical surface was split into 2 almost even segments. One of the split curves was selected and matched with the curve constructed in experiment 5.2.2.A.
- (2) To generate the 3D Regions, the two curves constructed above and the circle were selected in order that the cutting process could be held (Figure 5.13).

Outcome and analysis

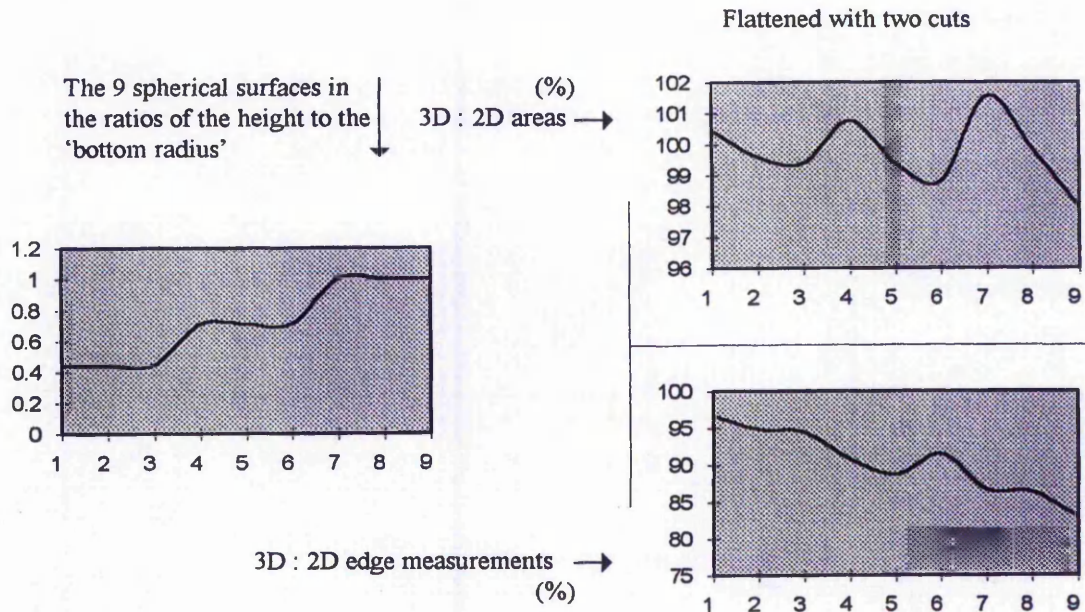
From the experimental results (Figure 5.14; Appendix 24) obtained, the distortion of the pattern areas was 1% higher than in the previous experiment 5.2.2.B (see Figure 5.12), but the distortion of the pattern edge measurements was about 7.5 % higher. This was because the latter total spherical surface was bigger so that more distortions were caused either in area or in edge measurements. Each of the two adjacent cut lengths also distorted differently. This showed the more the 'cuts', the less the pattern distortion. However, the degree of the improvement also depended on the position of the cuts. It was also found that each of the two adjacent cut lengths was inconsistent to each other. This implied that the flattened patterns were not yet ready for production use.

Figure 5.13 The spherical surface which was flattened with two cuts [5.2.2.C]



These two spherical patterns were flattened with two significantly different tensions and compressions. Apparently, the major spherical pattern (top) caused much more distortion than the small one (bottom).

Figure 5.14 Graphic illustration for 9 spherical surfaces in different height to the bottom radius ratios flattened using 2 cuts



The illustration showed that, the 9 sections of the sphere with 2 cuts, the accuracy of the pattern areas was within 98-100.5%, where as the accuracy of pattern edge measurements was within 82.9-94.8 %. This significant change was because the 2 cuts did not cut through the most convex surface.

The placement of these two cuts made the half sphere as two uneven spherical surfaces; the major spherical surface was flattened with much more stress and strain than was the smaller one. Therefore, the factors which could cause distortion in a flattened spherical surface were not just only the numbers of the cuts, but also the position of the cuts.

Experiment 5.2.2.D The dual bending condition

In experiment 5.2.1.E ('The single bending condition'), electronic flattening provided acceptable distortion for the 9 different types of cones with cuts. However, this distortion needed to be examined when the flattening subject had dual bending characteristics, e.g. a sphere. The experimental results imply the possible pattern distortion when electronic flattening was used to flatten a garment pattern.

Purpose

The purpose is to examine the changes in the pattern distortion when different bending depths of the spherical surfaces were flattened.

Processes

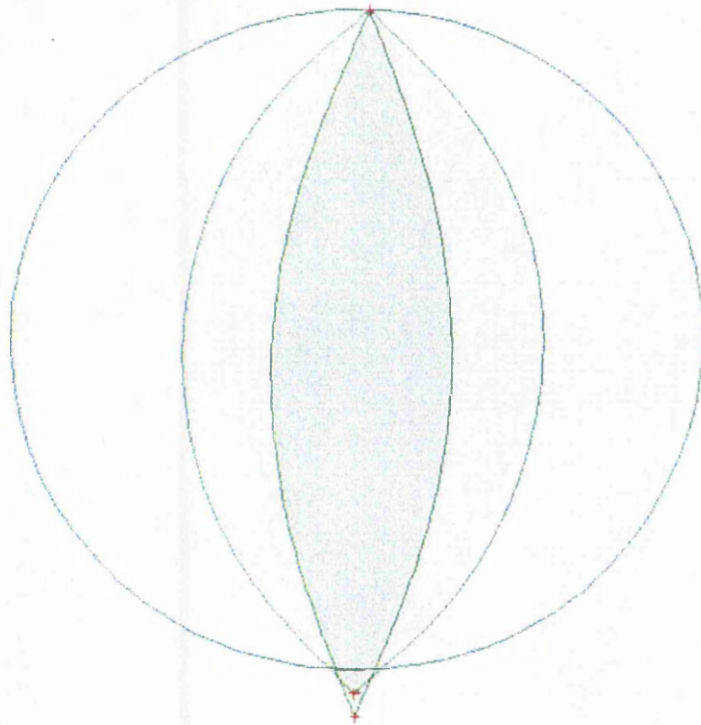
This experiment used only a sphere with a 18 cm radius. The three examined spherical surfaces were the three sections of $\pi/2$, $\pi/4$, and $\pi/8$ of the sphere. The first two surfaces were constructed in experiment 5.2.2.B (i.e. 'The dual bending form with one full cut'). The last one further divided the surface section of $\pi/4$ of the sphere into two even surface sections.

Outcome and analysis

The results in Figure 5.15 showed the pattern distortion increased in accordance with the depth and size of the surface sections of the sphere. The deeper the bending of the surface section of the sphere, the more the pattern distortion. This was particularly obvious in the distortion of the pattern edge measurements.

When applying this distortion condition to a garment pattern, it may be explained as the more the bending depth of the 3D pattern area (e.g. bust or blades), the more the distortion of the flattened 2D pattern. Therefore, pattern validity appears to be the only alternative to undertake because pattern distortion in the electronic flattening is bound to exist (see section 3.4.3, p.3-70) and cannot be predicted at this stage.

Figure 5.15 Pattern distortion in the 3 section surfaces of $\pi/2$, $\pi/4$, and $\pi/8$ of the sphere (of 18 cm radius)



The three patterns (from outward to inward) are respectively the flattened surfaces of segments of $\pi/2$, $\pi/4$, and $\pi/8$ of the sphere (of 18 cm radius). Clearly, the shallower and smaller the surface section of the sphere, the less the distortion of the 2D pattern edge measurements.

5.2.3 Discussion

The two main outcomes were that the flattened cone pattern shapes were irregular (see Figure 5.8) and a cut made in a 3D spherical surface did not always provide two identical cut lengths in the flattened pattern (see Appendix 22). This was the first indication that electronic flattening was deficient for garment pattern use at this stage. The reproductivity of the electronic flattening was examined using the same parameters (see experiment 5.2.1.C 'Outcome and analysis'), the results showed that the electronic flattening, at least, provided a 'consistent repetition' of distortion which manual pattern cutting would tend to be less. However, the consistent repetition of a 'deficient pattern' is even worse than that of the 'inconsistent' manually flattened pattern.

It was found that, for flattening a 3D basic form using the CDI-3D system, the changes of the tension and compression occurring in the spherical (i.e. dual bending form) surface were irregular and more than in the cone (i.e. single bending) surface (see Figures 5.9 and 5.12). Also, the flattened pattern shape was unstable if the flattening point of the 3D Region was selected differently (see Figures 5.6 and 5.15). If even flattening a basic 3D form can cause such a deficiency, it implies that the electronically flattened pattern would not be valid for garment use because 3D garment form curvatures would be much more irregular than a cone or sphere. The pattern distortion would be more difficult to predict and average.

Having acknowledged that certain levels of inaccuracies were bound to be caused when using different parameters of electronic flattening even for simple geometric forms, it was necessary to evaluate further applications in a practical garment form. The stability of the pattern shape and the actual changes of the pattern areas and edge measurements between 3D and 2D were the two main elements to be examined.

5.3 Electronic Pattern Accuracy and Shape Stability for Garments

Background to the experiments

From the experiments of flattening cones and spheres, two main considerations needed to be taken into account when applying the CDI-3D system for garment pattern making. These were the pattern accuracy and the pattern shape stability. Experiments on the pattern accuracy of the flattening used five different conditions, i.e. pattern flattening with a dart, with two darts, with a seam, with two seams, and with a dart plus a seam. These five experiments were designed to specify how electronic pattern flattening corresponded to the position and numbers of the dart and seam for the garment. Pattern shape stability experiments used one basic style cutting construction: the Princess style cutting. The selection of this style cutting was because it was known widely as a standard style and was designed particularly to fit women's bodies closely.

In order to identify clearly pattern changes between 3D and 2D, the experimental results in this section, i.e. the flattened patterns, were plotted out in the full sizes of the paper patterns. They were assessed primarily in two dimensions, then, the adjacent patterns were assembled using surgical tape, finally, the assembled patterns were assessed on the real sample garment form in three dimensions. Although pattern changes in the cone and sphere limited to pattern area or pattern edge measurements, it was deemed necessary to examine specific requirements for garment patterns. The garment dart and seam were used for this investigation because they were the two elements used to construct a close fitting garment. An investigation of two basic pattern design requirements, landmarks and grain lines, was made during the experiment in section 5.3.2.

The optimum parameters, gained from previous experiments, used for garment patterns are: the UV 'Surface display precision' as 12 x 12; the 'Mesh link length' as 7.5 mm; the 'gravity point' to begin flattening; the iterations as 10 'Layers', 25 'Total' counts, and the 'Final' count as 100. But, the software automatically chose the UV and the gravity point.

5.3.1 Electronic Pattern Accuracy

Electronic pattern accuracy becomes a factor when a 3D pattern is flattened or when a 2D pattern is moulded on to a 3D form; the flattened 2D pattern or the moulded 3D pattern has stress and strain. Pattern distortion (see section 3.4.3) is bound to exist when a 3D spherical surface (e.g. a 3D garment form) is flattened to a 2D planar surface (i.e. a 2D garment pattern). Importantly, in this study, an 'accurate pattern' is defined as a 2D garment pattern whose pattern edge measurements and pattern areas are consistent when it is as a 3D pattern.

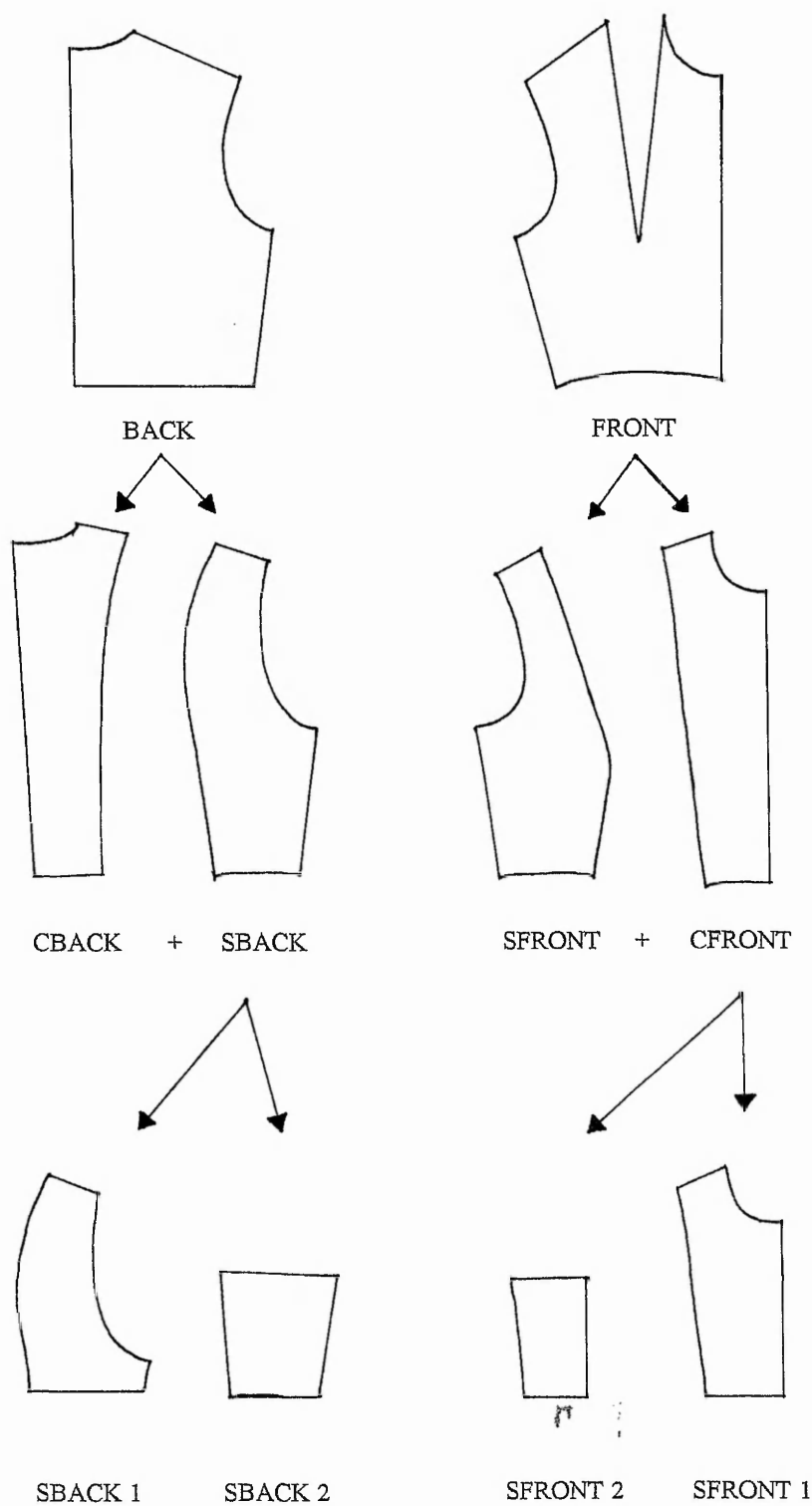
In order to evaluate this accuracy, the electronically flattened 2D patterns needed to be assembled together to represent its co-related 3D garment form. This assessment was demonstrated using paper patterns to reduce the subjective factors of the garment construction to a minimum. The assembled paper garment form was assessed on the sample garment form (see Figure 4.1) in the real world. This process was applied in five experiments (5.3.1.A~E). These five experiments focused on the front bodice pattern. If the front bodice pattern could be proved satisfactory in the electronic flattening, then the back bodice pattern would be relatively easy to flatten because it bends less than the front bodice in women's body construction.

In this section, five experiments were conducted as follows.

- Experiment 5.3.1.A Pattern flattening with a dart
- Experiment 5.3.1.B Pattern flattening with two darts
- Experiment 5.3.1.C Pattern flattening with a seam
- Experiment 5.3.1.D Pattern flattening with two seams
- Experiment 5.3.1.E Pattern flattening with a seam and 1-2 darts

Before discussing the experiments any further, it is necessary to establish a naming system for a sample pattern and each pattern piece for use throughout the whole process. The principle of naming a pattern piece was to adopt common terms in the garment industry in the UK. Details are illustrated in Figure 5.16.

Figure 5.16 The instruction for naming each pattern piece



Note The BACK and FRONT represent back and front bodice patterns. The abbreviations: 'C' refers to 'Centre' and 'S' refers to 'Side'. The numbers indicate the location and total numbers of the pattern pieces, the higher the number, the closer to the bodice side seam.

Experiment 5.3.1.A Pattern flattening with a dart

Purpose

The purpose is to evaluate how the placement of a dart affects the flattening of a 3D electronic pattern. The sample garment form was constructed using the primary and secondary control measurements which were established in section 4.3.

Processes

- (1) A dart was constructed using UV curves⁶ from the bust point respectively to the side neck point, the front armscye, side seam, and front waist which were the most commonly used garment dart positions. The four flattened patterns were named as Samples 1-4 (Figure 5.17). They were exported as AccuMark 300 compatible file format via the 'Translator' program (for details, see section 4.6).
- (2) The four pattern files⁷ on the floppy disk were imported into AccuMark 300 and then plotted out as full sized patterns through the connected plotter.
- (3) The dart of each Sample paper pattern was assembled using surgical tape. The dart position of Samples 1-3 was transferred manually from the side neck point, armscye, and side bodice areas to the front waist by cutting from the bust point to the waist line at 7.65 cm from the centre front. This is a commonly used 2D manual method of developing a pattern using a block.

Outcome and analysis

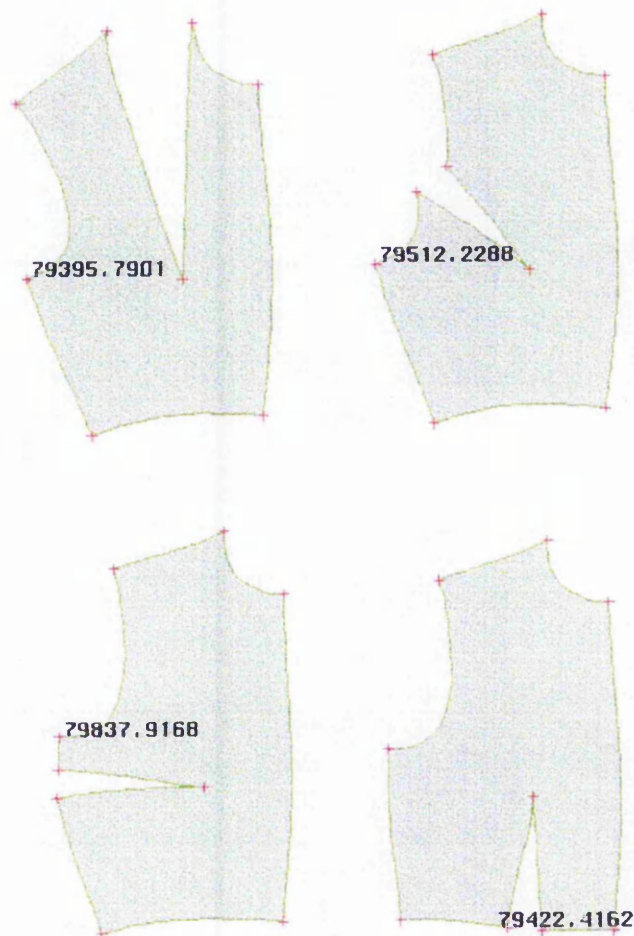
First, the pattern areas of the four Samples were all increased in comparison with the measurements of the 3D electronic patterns (see Figure 5.17).

Second, the tension and compression occurring in the four Samples were all very close to each other (Figure 5.18). In Samples 1-3 in which the dart positions were above the bust

⁶ In the CDI-3D system, the UV curve is one of the curve types which is used to construct any style design line in one 'Surface' (see sections 3.3.3.2 and 4.3.2.3).

⁷ The four patterns were then saved onto a floppy disk through the university academic network which was stated in section 4.6.

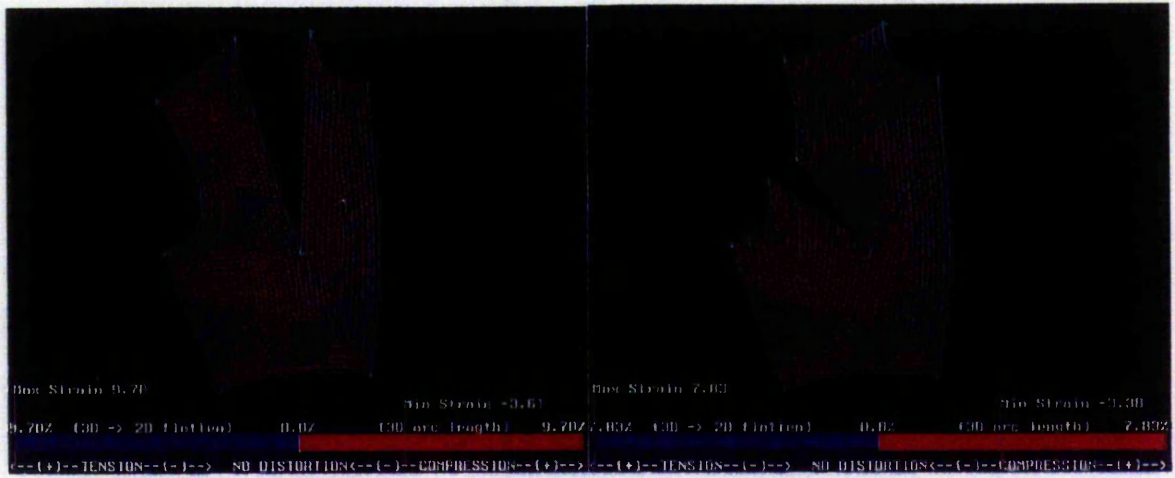
Figure 5.17 The four patterns which were flattened using one dart [5.3.1.A]



Top left : Sample 1
Bottom left : Sample 3

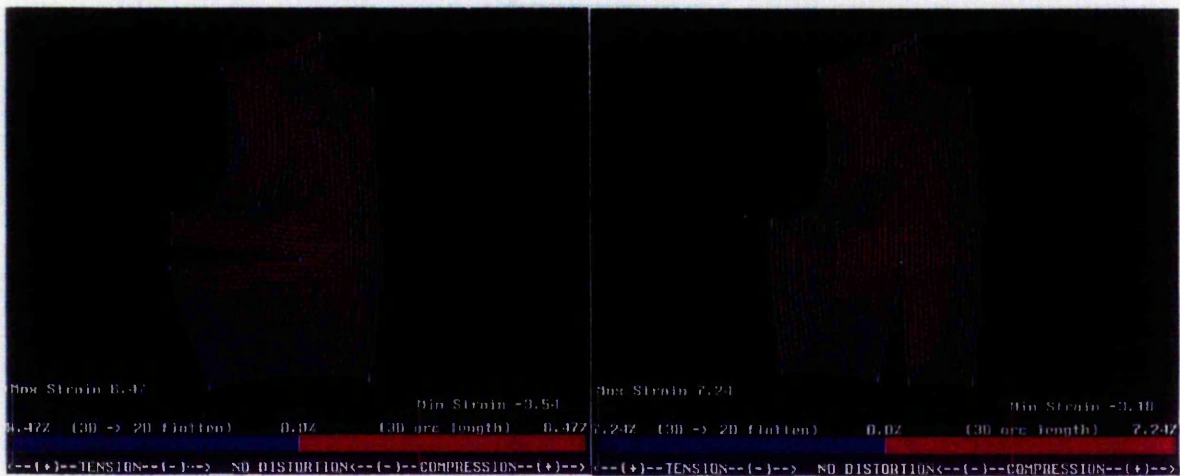
Top right : Sample 2
Bottom right : Sample 4

Figure 5.18 The tension and compression analysis of the four patterns which were flattened with one dart [5.3.1.A]



Sample 1

Sample 2



Sample 3

Sample 4

level, their compression during the pattern flattening was transferred to the left bottom of the bust area. Sample 4 had the dart position beneath the bust and its compression was transferred obviously above the bust level after flattening.

Third, none of the centre fronts of the four Samples was straight, however, the centre front measurement between the 3D pattern and the four flattened Samples was under 1 cm, e.g. in Sample 3.

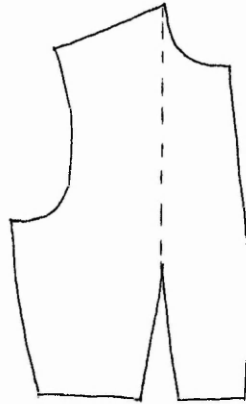
Fourth, amongst the four Samples, the two legs of each dart in two dimensions were found to have different lengths, respectively as 4.1, 4.3, 1, and 0.8 mm. This was particularly obvious in Samples 1 and 2 which had the dart at the side neck point and the front armscye area.

Fifth, when the four paper Sample patterns were assembled on the sample garment form, it was found that they would not sit flatly along the neckline although the pattern was only 1.5 mm less than the 3D neckline measurement. More importantly, the assembled dart areas in the four patterns were not flat, whereas in practice, they should remain the same.

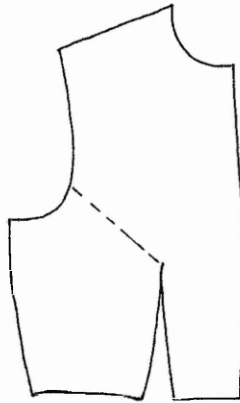
Finally, after manually transferring the dart position (from the side neck point, the front armscye, and the side seam) to the front waist, it was apparent that Samples 1-3 no longer stayed flat. Importantly, the new dart widths of Samples 1-3 became 4.7, 4.15, and 2.4 cm (Figure 5.19). Sample 4 remained at 3.7 cm. However, in 2D manual pattern cutting, when a 2D pattern is approved, the bust dart can be located in any position, and the 2D pattern still remains the same when returned to its original position.

The four flattened pattern shapes and the analysis of the electronic distortion showed that the analysis of compression and tension was not related directly to pattern shapes. Electronic distortion was only the mechanical analysis of the fabric when it was in a 3D formed or 2D flattened condition.

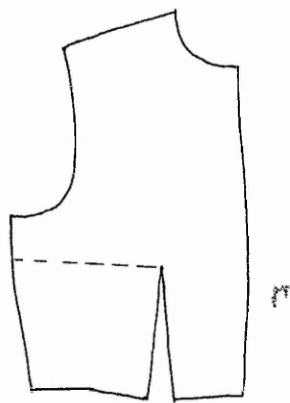
Figure 5.19 Dart transferring for Samples 1-3 [5.3.1.A]



Sample 1



Sample 2



Sample 3

Experiment 5.3.1.B Pattern flattening with two darts

This experiment focused only on the pattern with the dart at the side neck point. The second dart was selected for location at the front waist. These two dart positions were used widely to make a garment fit close to the bodice.

Purpose

The purpose is to examine the pattern changing condition when a single dart was divided into two darts. However, the dart construction in this experiment would represent the realistic garment dart construction in practice, i.e. approximately 2 cm away from the bust point. This was designed also to compare later with flattening pattern with a seam (see experiment 5.3.1.C).

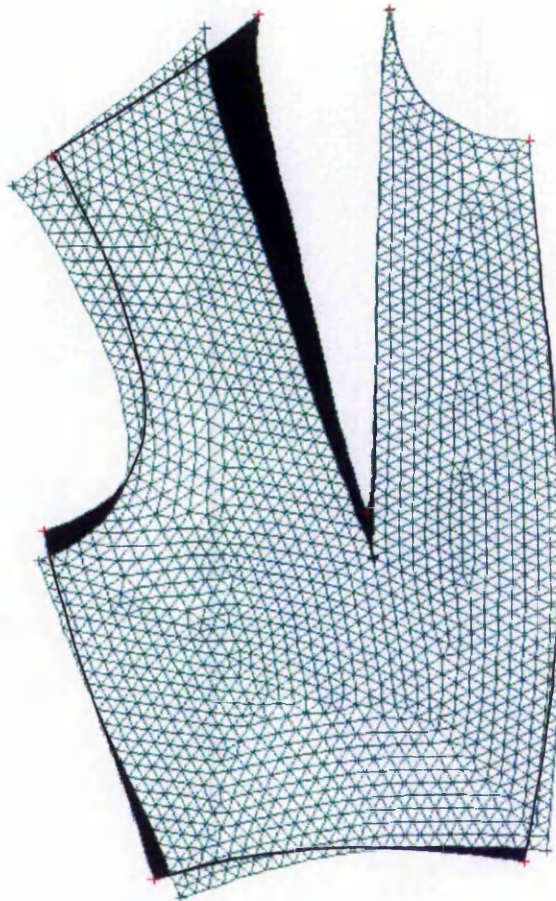
Processes

- (1) Sample 5 (Figure 5.20) was constructed and flattened the same as Sample 1 [5.3.1.A], but the dart was split approximately 2 cm away from the bust point to represent realistic dart construction for garment use.
- (2) For Sample 6 (Figure 5.21), the second dart was constructed and flattened from the bust point vertically down to the front waist using the UV curve. However, this second dart was also split approximately 2 cm away from the bust point in order that the two darts were not connected as a seam (see next experiment).
- (3) Two patterns were obtained. One was with only one dart opened at the side neck, and the other one was with two darts; one at the side neck and one at the front waist.

Outcome and analysis

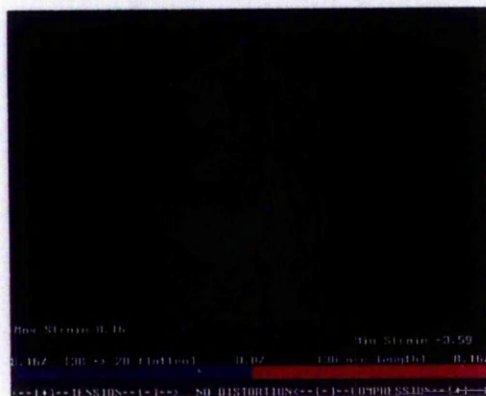
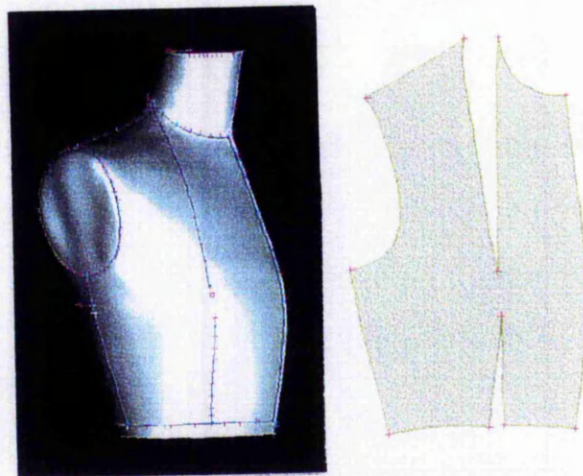
First, comparing Sample 1 [5.3.1.A] and Sample 5 [5.3.1.B] (see Figure 5.20), the dart width was changed from an original 9.20 cm (Sample 1) to 6.57 cm (Sample 5). This was because the dual bending curvatures at the bust area were not flattened completely due to the shortened 3D dart length.

Figure 5.20 The comparison between the two patterns which were flattened respectively with different dart lengths [5.3.1.B]



The pattern in green meshes was Sample 1 [5.3.1.A]; the pattern in solid black was Sample 5 [5.3.1.B].

Figure 5.21 Pattern flattening with two darts and its stress analysis [5.3.1.B]



Sample 6

Second, still comparing Sample 1 [5.3.1.A] and Sample 5 [5.3.1.B] (see Figure 5.15), the armhole shapes were kept similar to each other, but the underarm point and side waist point of Sample 5 were raised correspondingly due to the narrowed dart width. The centre front of Sample 5 was moved relatively inward and elongated. This pattern change was because the dart length of Sample 5 was shortened which meant that less curvilinear surface was flattened.

Third, comparing the FRONT of Samples 5 and 6 [5.3.1.B], when the dart was divided into two small darts, the dart width was changed from 6.57 cm to 3.71 and 1.57 cm; the wider dart width was located at the side neck, whereas the narrower dart width was located at the front waist. This was due to the different dart lengths; the longer dart length would relatively have a wider dart width, and vice versa.

Fourth, the centre front of Sample 6 was slightly more pronounced than in Sample 5 (Figure 5.22). This pattern change was because the side seam was relatively raised and constructed inward at the underarm point.

Finally, the measurements of the centre fronts of Samples 1 [5.3.1.A], 5 and 6 [5.3.1.B] all had different types of curvature. At this stage, it was still difficult to demonstrate that the centre front could be flattened as an absolute straight line as in a manually constructed garment.

Care must be taken that, from the investigation into 2D and 3D manual cutting a close fitting block (see section 2.4.2.2, pp.2-46 ~ 47; section 4.5.2, p.4-41) with curved, rather than straight, centre front and centre back would balance the waist suppression better. However, for mass garment production, straight centre front and centre back are used more often for better manufacturing solution.

Figure 5.22 The comparison between the two patterns which were flattened respectively with one and two darts [5.3.1.B]



The pattern in solid black was Sample 5 [5.3.1.B]; the pattern in green meshes was Sample 6 [5.3.1.B].

Experiment 5.3.1.C Pattern flattening with a seam

A seam, in the context of garment and garment pattern design, refers to a construction line which connects two garment patterns. This construction line could be simply for making a garment close fitting to the body or purely for emphasising the garment style line or decoration. In this case, the front is split into two parts with a commonly used seam through bust point from side neck point roughly vertically to hem (Figure 5.23).

Purpose

The purpose is to evaluate the difference in the electronic pattern flattening between flattening two darts and flattening a seam.

Processes

The main processes of constructing and flattening this pattern were exactly the same as in Sample 6 [5.3.1.B]. The seam was constructed by joining the two darts using the 'Join' program under the 'Curves-Edit' program. This seam divided Sample 6 as Centre Front ('CFRONT') and Side Front ('SFRONT') [5.3.1.C]. The two patterns were connected at the bust point as the FRONT of Sample 7 (see Figure 5.23).

Outcome and analysis

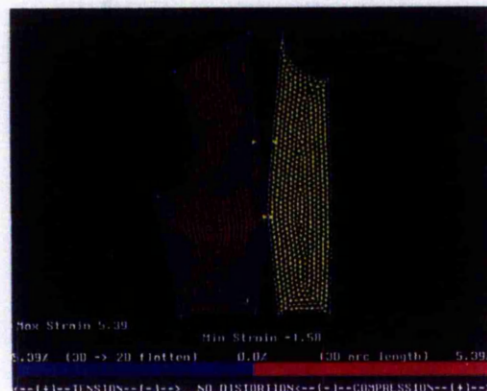
The great significance of Sample 7 was that its centre front had almost obtained a straight line. This change shortened the length from 37.04 cm (of Sample 5 [5.3.1.B]) to 35.82 cm. Also, SFRONT 1 was almost identical as a part of the FRONT of Sample 5 [5.3.1.B] when both patterns were overlapped (Figure 5.24).

When comparing Sample 7 [5.3.1.C] to Sample 5 [5.3.1.B], the tension and compression of Sample 7 appeared to be reduced because the major pattern width was wider (see Figure 5.24). The pattern area and edge measurements of Sample 7 were slightly smaller than Sample 5's [5.3.1.B]. Importantly, in Sample 7, the upper dart of the seam line at SFRONT appeared to have more discrepancies than at CFRONT. This seam gave a better quality of pattern accuracy, i.e. a better result of fit quality.

Figure 5.23 Pattern flattening with one seam [5.3.1.C]



The CFRONT (right) of Sample 7 showed that the front neck girth was compressed and shortened.



The SFRONT (left) of Sample 7 showed an elongated front seam area and stressed in the bust area.

Figure 5.24 Comparing the two patterns which were flattened respectively using two darts and one seam [5.3.1.C]



The pattern in solid black was Sample 5 [5.3.1.B]; the pattern in green meshes was Sample 7 [5.3.1.C].

Experiment 5.3.1.D Pattern flattening with two seams

Having acknowledged the contribution of a seam to a close fitting garment, it was regarded as important to investigate how a second seam could assist in obtaining a better flattened pattern from the 3D-PDS.

Purpose

The purpose is to examine how the construction and flattening of the patterns and the degree of close fitting would change when using a second seam. More importantly, to investigate whether the position of the seam would affect a pattern.

Processes

Three types of 2-seam placement on the front bodice patterns were made by switching the two seams at different places. The processes were as follows:

- (1) In Sample 8 (Figure 5.25), the first seam was constructed from approximately the mid shoulder over the bust point to the front waist, this created CFRONT and SFRONT. Then, the second seam divided the SFRONT into two smaller patterns, namely, the SFRONT 1 and 2.
- (2) In Sample 9 (Figure 5.26), one seam was developed by constructing approximately from the mid shoulder across the bust point to the front waist; the other one was constructed horizontally at the bust level. This developed 4 pattern pieces: CFRONT 1-2 and SFRONT 1-2.
- (3) In Sample 10 (see Figure 5.26), one seam was developed by constructing it exactly the same as the pattern with the other seam switched from the bust level to the across front level. This developed 4 pattern pieces (similar to above): CFRONT 1-2 and SFRONT 1-2.

Figure 5.25 Pattern flattening with two seams: one was at the front convex measurement, the other one was at the front side bodice [5.3.1.D]

After placing the first seam

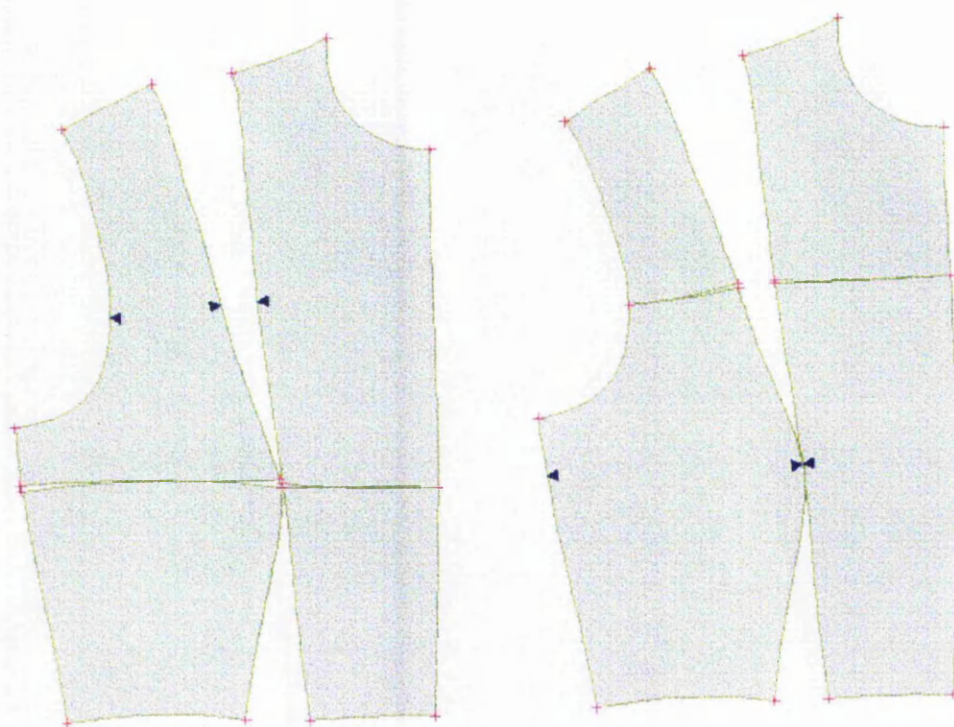


After placing the second seam



Sample 8, after placing the second seam, the front seam length at SFRONT 1 (mid bottom) was slightly shorter than the one at the SFRONT (left top).

Figure 5.26 Pattern flattening with two seams which were switched at the front convex measurement, front bust girth, and across front area [5.3.1.D]



Left : Sample 9 = CFRONT 1-2 + SFRONT 1-2.
The SFRONT in Sample 9 was with two opened areas at the front and side seams.

Right : Sample 10 = CFRONT 1-2 + SFRONT 1-2
The front seam did not have much change in the SFRONT of Sample 10.

Outcome and analysis

First, in SFRONT 1 of Sample 8 (see Figure 5.25), the seam length from mid shoulder across the bust point to the front waist was 1.6 mm shortened in comparison with the same seam constructed in SFRONT pattern of Sample 8. The tension and compression of the pattern flattening were reduced. This showed that the pattern with two seams would represent more closely the corresponding 3D pattern than would a pattern with one seam.

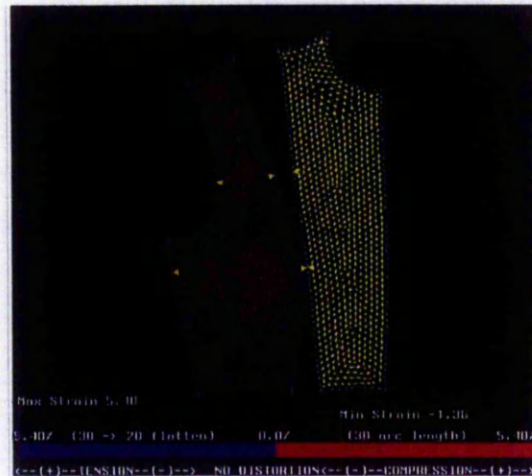
Second, the inconsistency of the two adjacent seam lengths between the CFRONT and SFRONT of Sample 8 (see Figure 5.25) was 4.3 mm, but it was 2.6 mm between CFRONT and SFRONT 1 of Sample 8 (see Figure 5.25) although they all had the same seam length when they were 3D patterns. The strain analysis after the placements of the first and second seams was compared in Figure 5.27. In this case, it was noticed that the second seam divided the side front bodice which had an obvious rounded curvature. This meant that the depth of the section of the spherical surface was more shallow, so the flattened results gave a better quality of fit.

Third, the inconsistency of the two adjacent seam lengths was 2.6 mm for Sample 8 (see Figure 5.25), 0.3 mm for Sample 9 (see Figure 5.26), and 3.9 mm for Sample 10 (see Figure 5.26). When averaging this inconsistency for each Sample, the seam length became 41.29 cm for Sample 8, 40.96 cm for Sample 9, and 41.28 for Sample 10. The seam length which was constructed in the 3D pattern was 40.95 cm. The pattern areas and edge measurements in Samples 8-10 were very close to each other (respectively as 792.83, 792.86, and 793.26 square cm.). This illustrated that the placement of the second seam in Samples 9-10 did not change much from Sample 8. This meant that the position of seam affected pattern accuracy more than the numbers of seams.

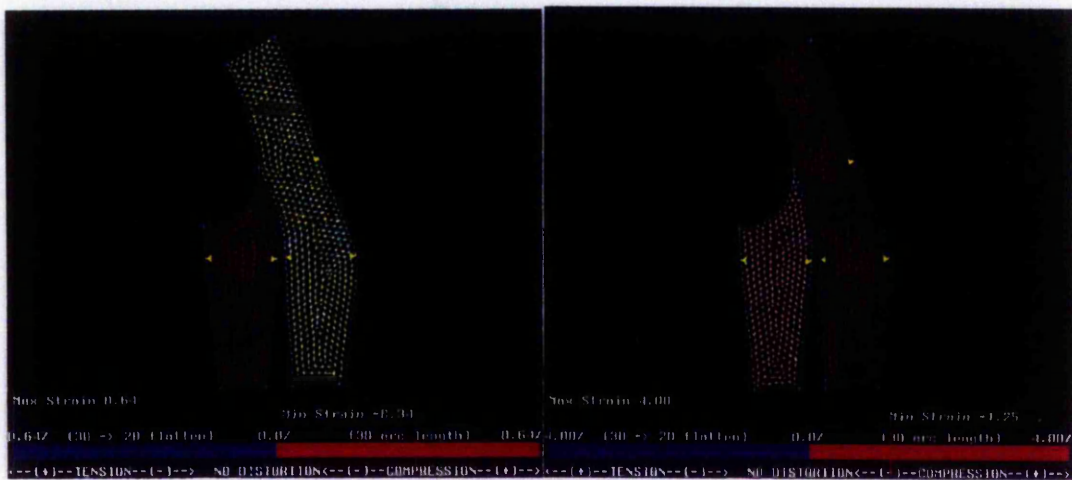
The experimental results showed that the changes of the pattern shapes, areas, and edge measurements were determined by the numbers and the positions of the cuts, whereas a pattern cutter has to be able to cut a pattern as the style demands and still retain the shape and pattern edge measurements of the garment from.

Figure 5.27 The stress analysis after the placement of the first and second seams for Sample 8 [5.3.1.D]

Placing the first seam on the FRONT bodice pattern



Placing the second seam on SFRONT of the FRONT bodice pattern



Placing a seam at a dual bending area could reduce the tension and compression of the flattened patterns.

Experiment 5.3.1.E Pattern flattening with a seam and 1-2 darts

Purpose

This is to evaluate the electronic flattening result when applied to garment pattern construction with a seam and 1-2 darts.

Processes

A seam was constructed from the front neck point bias to the bodice side seam approximately 7 cm below the under armpit point. This created Sample 11 (Figure 5.28) which consisted of the FRONT of Upper ('UFRONT') and Lower ('LFRONT') patterns.

Then, an extra dart was constructed at the side front area of the LFRONT pattern piece using four different dart lengths. This created LFRONT 1-5 of Sample 11 (see Figure 5.28); LFRONT 5 was divided into 2 pattern pieces by a seam.

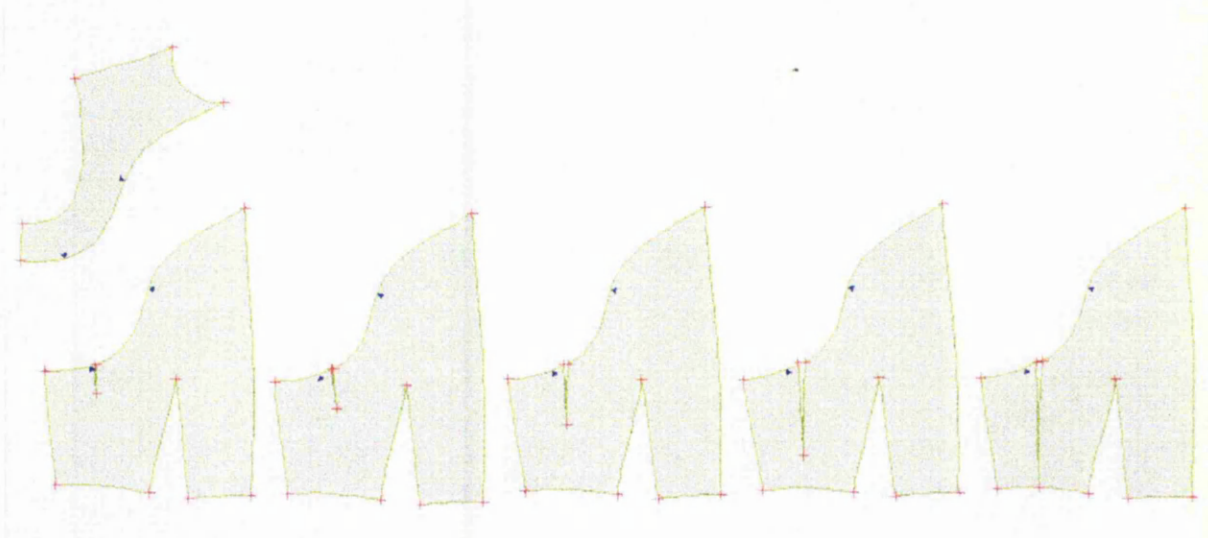
Outcome and analysis

Figure 5.28 showed that the greater the dart length, the wider the dart width will open on flattening. This will affect simultaneously the 3D pattern areas which decrease gradually in accordance with the changes of both dart widths from narrow to wide.

In LFRONT 1-5, in the dart at the front waist, each of the two dart legs, on average, had 2-3 mm inconsistency to each other. The dart widths at the front waist were increased in accordance with the increasing of the dart lengths and widths of the extra dart. In garment pattern making, the two adjacent pattern edges for a seam can be inconsistent to each other (e.g. when the two adjacent patterns have different grains or fabric properties), but the two adjacent dart legs are always the same.

The adjacent pattern boundaries of the UFRONT and LFRONT 5 (see Figure 5.28) were consistent when assembled, so were the rest of the other four patterns. This experiment reinforced (see experiments 5.3.1.A~B) that the use of a garment dart does not appear to be achievable by adapting the current CDI-3D system because the software would curve the centre front to distribute the distortion (see '5.3.3 Discussion', p.5-64).

Figure 5.28 Pattern flattening with 1 seam and 1-2 darts [5.3.1.E]



Sample 11 = 'UFRONT + LFRONT' together with five pattern pieces LFRONT 1-5 (LFRONT 5 consisted of 2 pattern pieces).

In the second dart of LFRONT 1-5, it showed that the longer the dart constructed, the wider the dart width would be obtained, simultaneously, the 3D pattern areas were decreased from narrow to wide dart length.

5.3.2 Pattern Shape Stability

It was acknowledged that, in theory, it is impossible to keep both the pattern surface area and the pattern edge measurements constant so that they remain identical on converting from 3D to 2D (see section 3.4.2.2). Up to the present, the experiments in this study were focused mainly on investigating the uses of the flattening parameters and the pattern accuracy between 3D and 2D pattern areas and edge measurements. However, it is essential to realise that having a consistent pattern area or pattern edge measurements *does not produce one 2D pattern shape only*. Therefore, it is important for a garment pattern designer to examine an electronically flattened pattern.

Prior to undertaking the experiments, it was essential to investigate how the system assigned the landmarks and the grain line to a pattern piece during the flattening process. The landmarks and the grain lines control the relationship between patterns, and the grain line also controls fabric behaviours with reference to the style. This is determined at the early stage of garment design. It was found that these pattern design requirements were not available in the system until the later stages when the pattern pieces had already been developed. It was also seen as important that once a basic pattern shape was accepted, simple dart or seam re-location should not change the shape of other edge measurements and areas of the pattern.

Three main groups of experiments in this section were designed to examine the creation of pattern shapes and their variations. First, when the mesh node (see experiment 5.2.1.C) flattening parameter was changed. Second, when darts or seams were used in one particular garment pattern style. Finally, when basic darts or seams were constructed in the back bodice pattern.

In this section, the three experiments were conducted as follows.

Experiment 5.3.2.A The mesh node in relation to the flattened pattern shape

Experiment 5.3.2.B Pattern flattening with one particular style line

Experiment 5.3.2.C Pattern flattening with two style lines

Experiment 5.3.2.A The mesh node in relation to flattened pattern shape

As stated in section 3.5 (see Figure 3.27, p.3-75) and obtained in the outcome of the experiment 5.2.1.C (p.5-47), the selection of which starting mesh node to use for flattening would affect the flattened pattern shape.

Purpose

This experiment is to evaluate how pattern shape would be changed when selecting a different mesh node to begin flattening.

Processes

1 The side front bodice pattern was selected for the demonstration in this section because it provided a better illustration of the pattern shape variations.

2 Eight different positions for the mesh node were selected (at the five angular points of the side bodice pattern piece, plus the bust point, the front armpit point position, and the gravity point which the system could select by itself). This created SFRONTS 1-8 of Sample 12 (Figure 5.29).

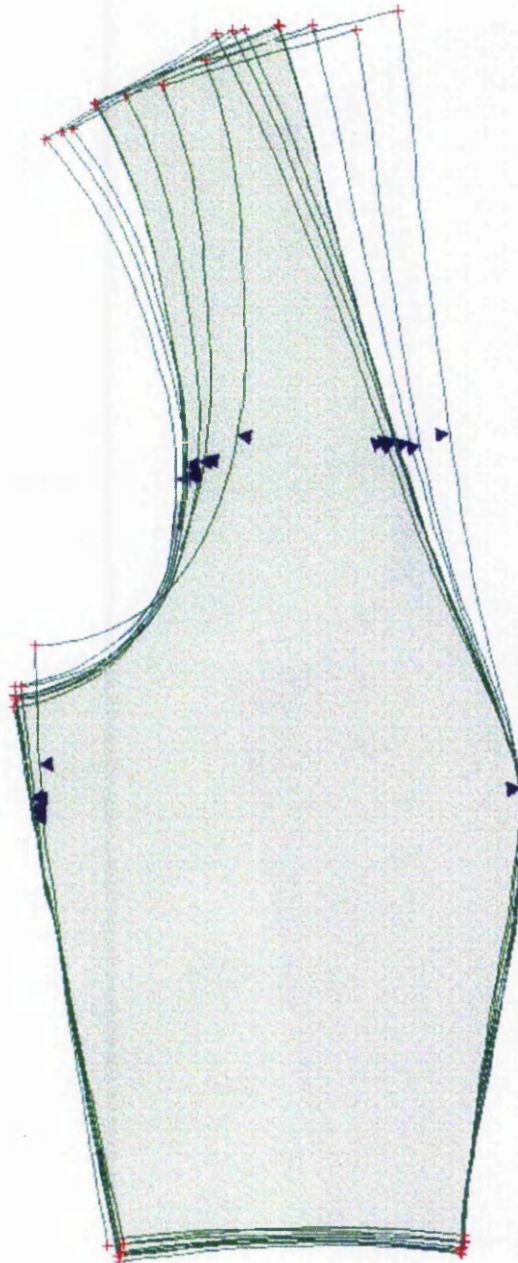
Outcome and analysis

The 8 SFRONTS were stacked at the bust point. All the pattern shapes were different, except that SFRONTS 4 and 5, which were flattened from the gravity point and the side waist point, were almost identical to each other (see Figure 5.29).

The front seam length of SFRONT 7, which was flattened from the mid waist area, was 6 mm shorter than the measurement on the 3D pattern. This caused its armscye girth to be 5 mm bigger than in the 3D pattern. In comparison with the 3D pattern, the differences of the seam lengths of the 8 SFRONTS varied from -6 mm to 11 mm (see Figure 5.29); the armscye girths changed correspondingly, but not as much as the changes on the front seam length. Hence, pattern edge measurements and shapes affected pattern accuracy. Also, the system provided an intermediate pattern shape, i.e. the pattern which was flattened from the gravity point appeared to be a mean pattern amongst the 8 SFRONTS.

Figure 5.29 The 8 SFRONTS which were flattened using different mesh nodes [5.3.2.A]

The solid pattern was the one which flattened from the gravity point of the pattern.



Sample 12 = SFRONTS 1-8 (left to right). They were flattened respectively from the areas of: (1) armpit, (2) mid armscye, (3) shoulder point, (4) gravity point, (5) side waist, (6) mid shoulder, (7) mid waist, (8) bust point.

The seam lengths were (left to right): 42.06 41.96 41.79 41.51 41.43 41.02 40.34 40.87
 The armscye girths were (left to right) : 22.26 22.26 22.27 22.63 22.63 22.64 22.84 22.83

Experiment 5.3.2.B Pattern flattening with one particular style line**Purpose**

To evaluate the pattern shape variations if a seam is moved to a different position and to investigate the grain assignment.

Processes

One-piece 3D front and back bodice patterns were constructed from the 3D garment form. The Princess style line was constructed from the middle front armseye across the bust point to the front waist. This created CFRONT and SFRONT of Sample 13 (Figure 5.30). The back bodice pattern was constructed in a similar way. The created patterns were CBACK and SBACK of Sample 14 (see Figure 30).

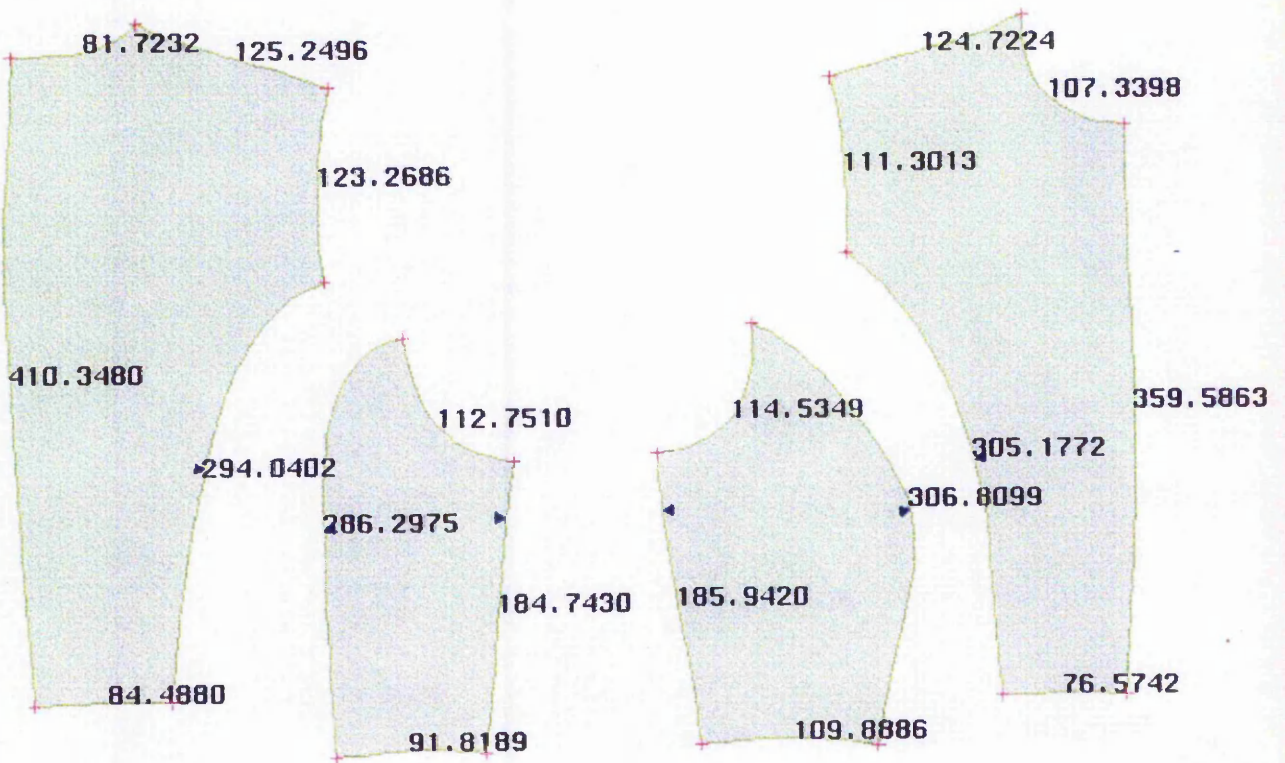
Outcome and analysis

The mutual pattern boundaries of CBACK and SBACK (of Sample 14) showed 7.7 mm of inconsistency to each other. This inconsistency of the adjacent pattern edges appeared to have occurred equally at the armseye and waist. When assembling both patterns by matching at the key marks, it was found that the assembly also created a severe 3D form at the back armseye area which was originally to provide room for the blade. This reinforced the point (see experiment 5.3.1.D) that the position of seam affected the quality of the flattened pattern.

The front neck girth of CFRONT (of Sample 13) and the back neck girth of CBACK (of Sample 14) respectively were 2-3 mm shorter. When assembled, it was apparent that the neck girth would not fit properly along the neckline of the real sample garment stand.

The FRONT was found to fit better than the BACK when assembled on the real sample garment form. The main reason for this could be that the placement of the back bodice seam did not provide room in the correct position.

Figure 5.30 Pattern flattening with one particular style line [5.3.2.B]



Sample 13 = CFRONT + SFRONT; Sample 14 = CBACK + SBACK.
The back seam lengths between CBACK and SBACK were significantly inconsistent each other.

Experiment 5.3.2.C Pattern flattening with two style lines

Purpose

To assess the distortions of the back seam of Sample 13 using variations of dart and seam placements and to compare them with the FRONT of Samples 9 and 10 (see Figure 5.26).

Processes

Four BACK bodice patterns were constructed with two darts, 1-seam, and two 2-seams. The developed patterns were named respectively as Samples 15-18 (Figure 5.31).

Outcome and analysis

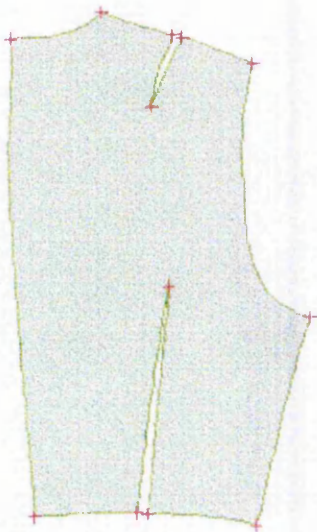
In Sample 15 (see Figure 5.31), the two darts (i.e. at the mid back shoulder and waist) were opened less when compared with the basic block construction for close fitting garments (see section 2.4). Also, the armscye girth was elongated about 5 mm more than that of Samples 16-18, and about 11 mm more than the measurement of its 3D pattern. The bodice side seam and back neck girth were both shortened significantly.

Second, the back seam in Sample 16 improved the fitting degree of the back armscye girth (of Sample 15) from 11 mm to 4 mm. This provided room in the shoulder blade area which justified the last statement in the earlier experiment 5.3.2.B. All the pattern edge measurements were closer to the measurements for their relevant 3D patterns. The tension and compression of the flattened patterns were also reduced. This reinforced that cutting a pattern using a seam gave a better fit quality than that using darts.

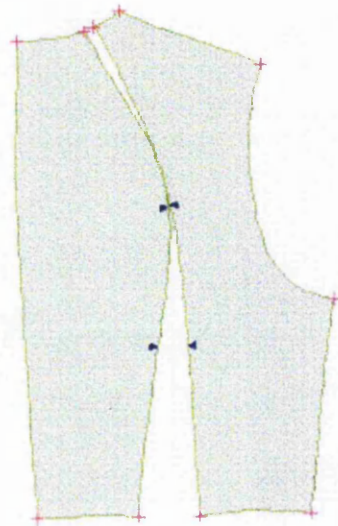
Third, the armscye girth of Sample 17 was about 6 mm more than its 3D pattern; Sample 18 was about 3 mm more than its 3D pattern because the second seam at the back armscye assisted in flattening the dual bending blade area.

Finally, comparing the BACKs with the FRONTS of Samples 6-7 and 9-10 (see experiments 5.3.1.B~D, Figures 5.21, 23 and 5.26), the similarities were that: pattern flattening with darts produced deficient patterns for garment use and the positions of the seams affected the contact-fit quality of the flattened patterns.

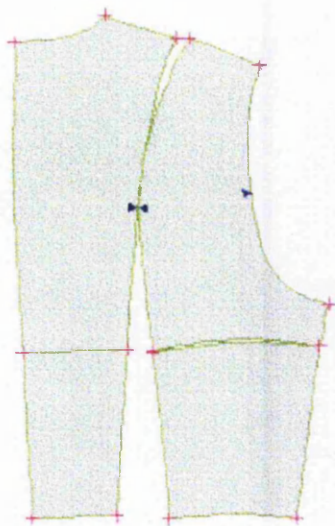
Figure 5.31 The four BACK bodice patterns which were constructed respectively using 2-dart, 1-seam, and two 2-seams [5.3.2.C].



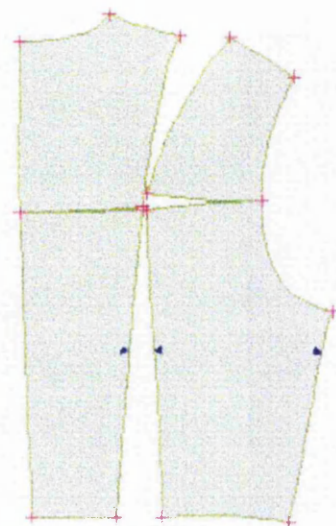
Sample 15



Sample 16 = CBACK + SBACK



Sample 17 =
CBACK 1-2 + SBACK 1-2



Sample 18 =
CBACK 1-2 + SBACK 1-2

5.3.3 Discussion

Having looked at CDI electronic flattening process, now it needs pattern expertise to explore gaps in the system. In garment cutting, the construction of a garment dart for a close fitting garment usually ends approximately 2 cm away from the bust point (see section 2.4.2, p.2-46); also, two bust darts could be used to replace the use of a seam to make a garment close fitting. However, the experiments did not provide the same solution (see experiments 5.3.1.A~C). Importantly, the discrepancy of the seam line was significant (see Sample 7 in Figure 5.23, p.5-48). This was because the electronic flattening program developed each pattern as an individual pattern piece. Although the system provides 'Seam' and 'Join' functions to rectify the discrepancy of the two adjacent pattern edges, it is limited in offering criteria to determine which pattern edge can conform to the attempted 3D form.

Experiment 5.3.2.A illustrated the variations of the pattern shape when selecting different points to begin the flattening. Although the pattern which was flattened from the gravity point seemed to be the best average pattern shape amongst the eight patterns, there did not appear to be any means by which a designer could evaluate it at this stage. Very importantly, electronic flattening seemed to focus on attempting to keep the pattern area and edge measurements differences between 3D and 2D patterns to the minimum possible, but ignored the reality of a garment pattern designer's methods of controlling the pattern shape (see experiment 5.3.2.C, Figure 5.31). The manually constructed garment pattern is proved by garment pattern cutting expertise, whereas this expertise, i.e. pattern validity technique, does not appear to be available in the current pattern design system.

Finally, it is necessary to remember that, in the CDI-3D system, the landmarks and the grain line were not available until the later stages when the pattern pieces had already been developed (see experiments 5.3.2.A~C). This meant that a designer could not determine the landmarks and the grain line earlier in the garment design stage (for details, see section 6.4.4). Having seen so many inconsistent pattern distortions, it was vital that reasonable electronic pattern distortions for producing garment patterns with quality fit could be identified (see p.6-12).

5.4 Comparing the Electronic and Manual Foundation Patterns

Background to the experiments

From the previous experiments, it was apparent that the pattern accuracy and pattern shape stability when flattening electronic patterns could be diverse. It was necessary that this diversity should be investigated and compared with the accuracy and stability of manually toiled patterns.

The sample garment form was, hence, created for carrying out this investigation (see section 4.2). The 3D surface data of the created sample garment form data were collected using the LASS (see sections 4.3.2.1~3). An identical sample garment form was created in the CDI-3D (see section 4.4). A particular garment pattern construction was stabilised on the real sample garment form (see section 4.5.2), so that, later, electronic pattern construction could be established comparatively. The four foundation patterns were toiled manually⁸ (see section 4.5). These four manually controlled patterns were used to compare with two groups of electronically flattened patterns.

The gravity point of the electronic patterns was selected for flattening because it provided an intermediate pattern shape amongst the eight patterns (see experiment 5.3.2.A), particularly, it also appeared to be consistent with the manually toiled foundation pattern shape (Figure 5.32). The comparisons made in the following experiments were:.

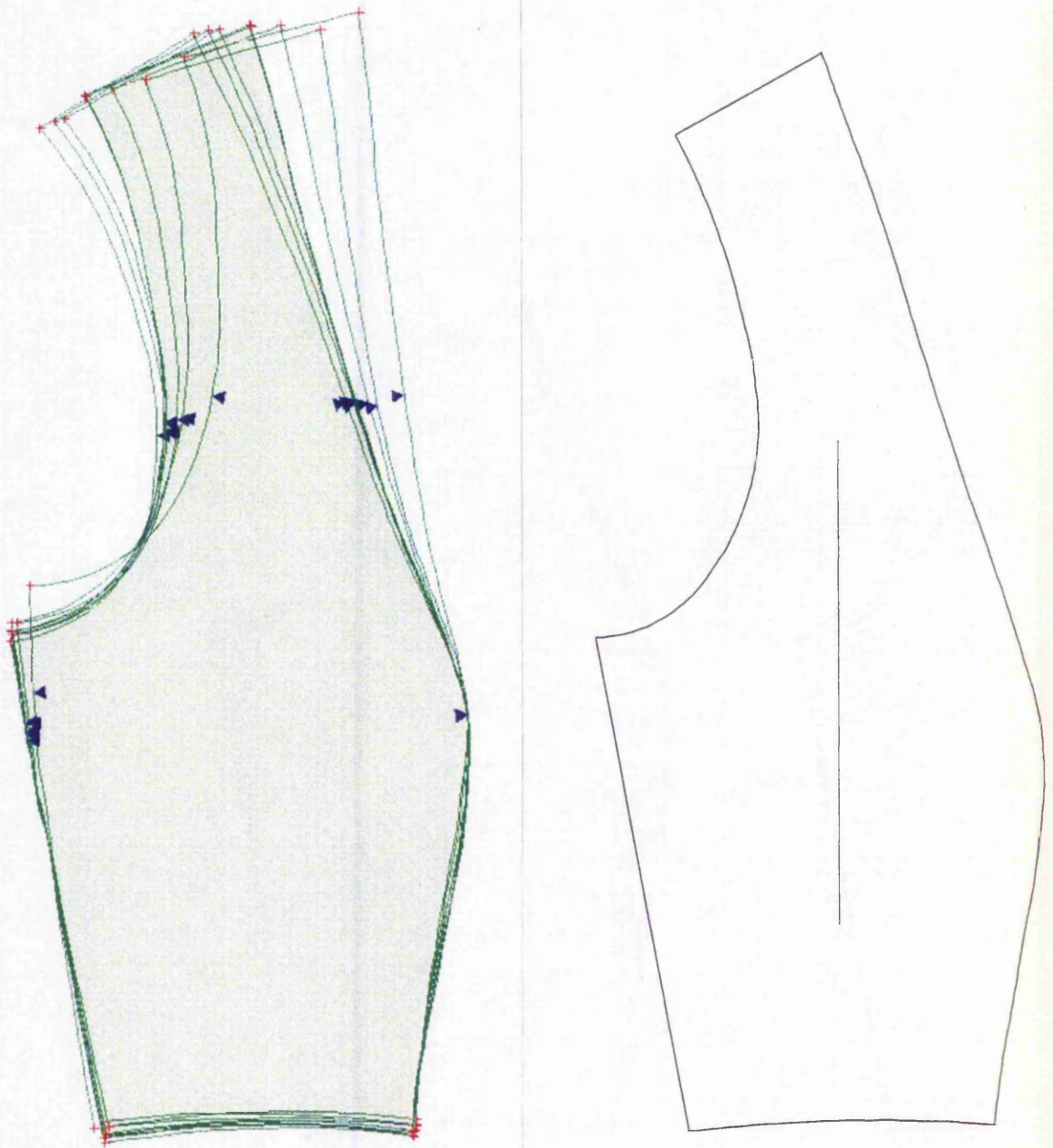
- Experiment 5.4.A ‘Standard’⁹ flattened patterns with manual patterns
 Experiment 5.4.B ‘Edge-matched’¹⁰ with ‘Standard’ flattened patterns and with manual patterns

⁸ Although it was realised that using more seams to take-off a 3D garment pattern would obtain a pattern more accurately, in order to reduce human error variables to a minimum, four seams were used to toile the created sample garment form.

⁹ The ‘Standard’ flattening process used five basic parameters to flatten patterns (see section 5.3, p.5-34).

¹⁰ The ‘Edge-matched’ process is similar to the ‘Standard’, except when selecting the ‘Edge’ matched function before flattening. The flattened 2D pattern edge measurements will be identical to a 3D pattern’s.

Figure 5.32 The pattern which was flattened from the gravity point appeared to be comparatively consistent to the manually toiled pattern shape



The solid pattern in the middle (left picture) which was flattened from the gravity point showed more consistency compared to the manually toiled pattern (right picture).

Experiment 5.4.A 'Standard' flattened patterns with manual patterns

Purpose

This is to examine the reality of an electronically flattened pattern by the 'Standard' parameters and processes (i.e. used in those previous experiments) by comparison with manually toiled patterns.

Processes

Both manual and electronic patterns were constructed and controlled through the 16 control measurements (see section 4.4.).

(1) The four CDI-3D patterns were flattened as for Sample 19 (Figure 5.33), using the same parameters as in previous experiments. The CDI flattened patterns were plotted out as Sample 19-P (paper) and Sample 19-C (calico).

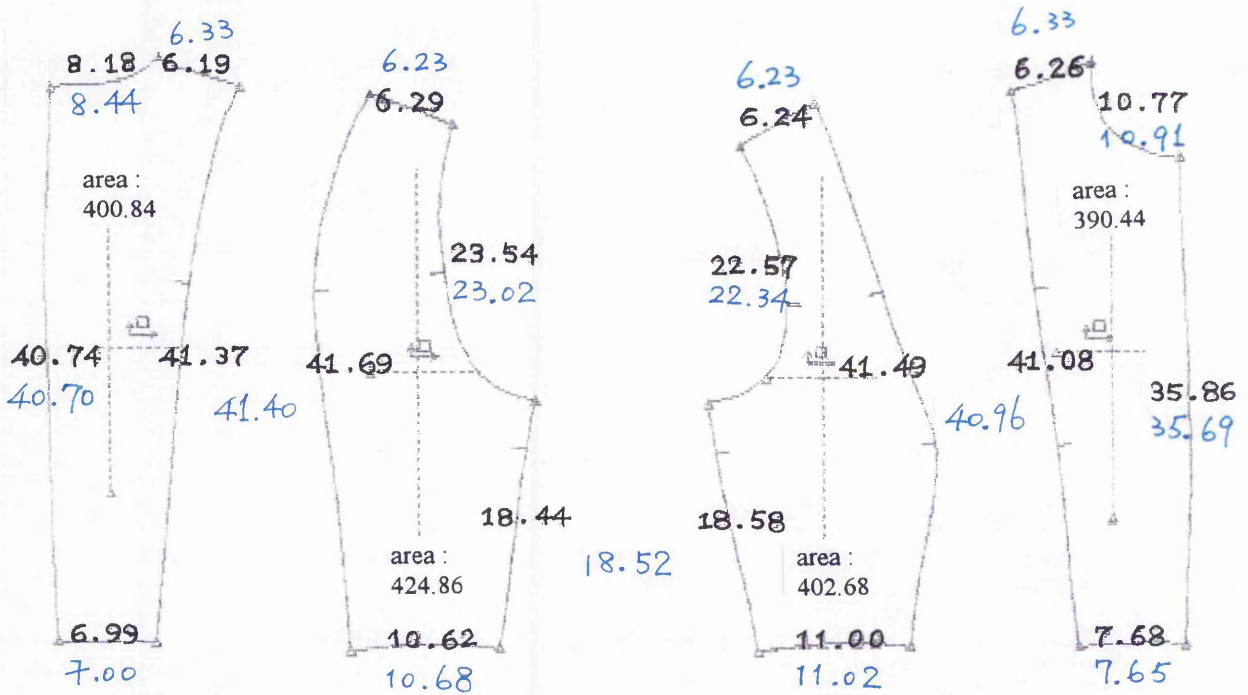
(2) The manually toiled patterns (see section 4.5.6.1) were plotted out as for Sample 20-P (paper) and Sample 20-C (calico) (see Figure 5.33).

Outcome and analysis

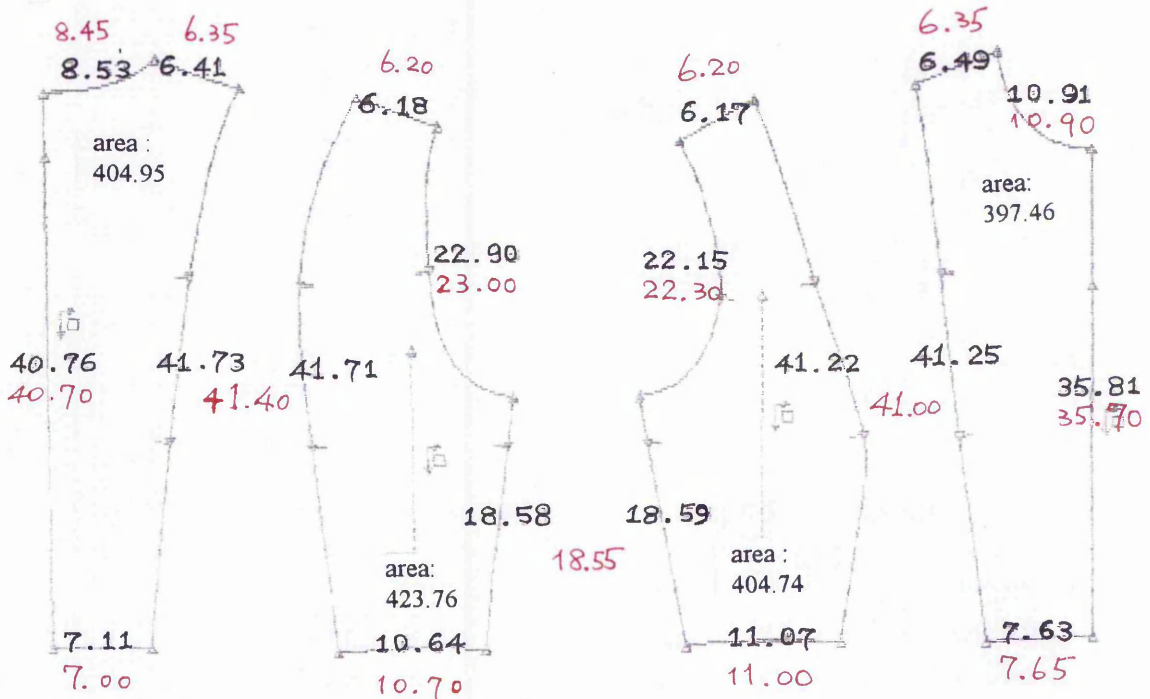
First, the tension and compression of CBACK, SBACK, and SFRONT (of Sample 19) were about 5 %; CFRONT's were less than 3 % (Figure 5.34). The centre front and back of Sample 19-P (electronic) were obviously rounded, whereas those of Sample 20-P (manual) were controlled to be straight (Figure 5.35). However, one has to realise that the rounded or straight centre front must be optional (see pp. 2-46~47; 4-41; 5-45).

Second, Figure 5.33 showed that the maximum inconsistent measurement (of pattern edge measurements) between 3D and 2D was approximately 1.4 mm by manual and 2.6 mm by electronic methods, except that the inconsistency of the two convex measurements was 2.5-3.3 mm by manual and 0.3-5.3 mm by electronic methods. Total pattern periphery was not considered for it is of no use to garment pattern cutting. Importantly, none of the measurements were identical for 3D and 2D patterns. This meant that, with only 1 seam at FRONT, pattern distortion and inconsistent pattern edge measurements were bound to exist. Parameters and manual cutting expertise were needed to rectify these deficiencies.

Figure 5.33 The CDI-3D 'Standard' flattened patterns and manually toiled foundation patterns which were cut out using calico [5.4.A]

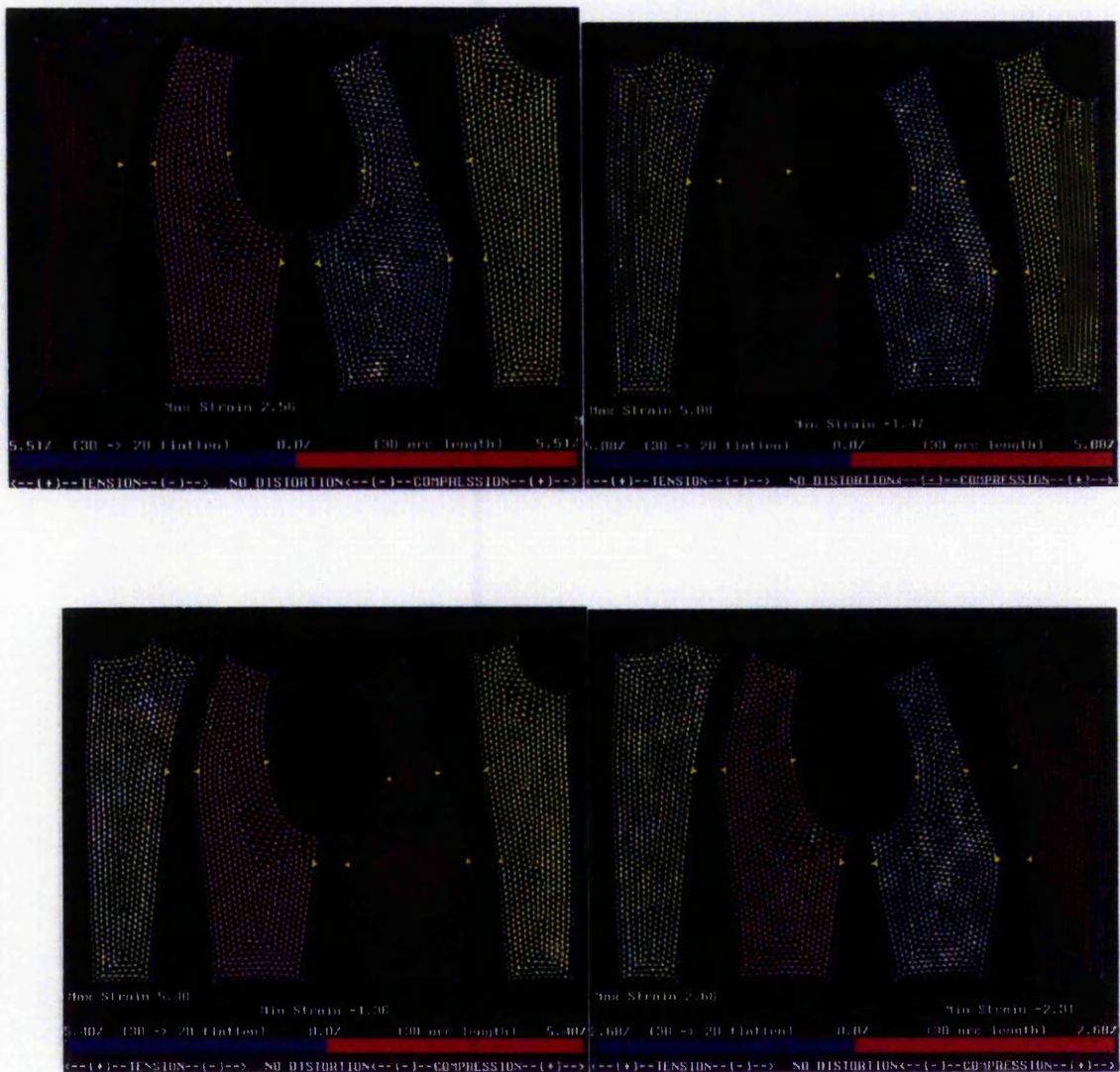


(CDI-3D 'Standard' flattened) Sample 19-C = CBACK + SBACK + SFRONT + CFRONT
The blue figures are the measurements for 3D pattern; the black figures are for 2D pattern.



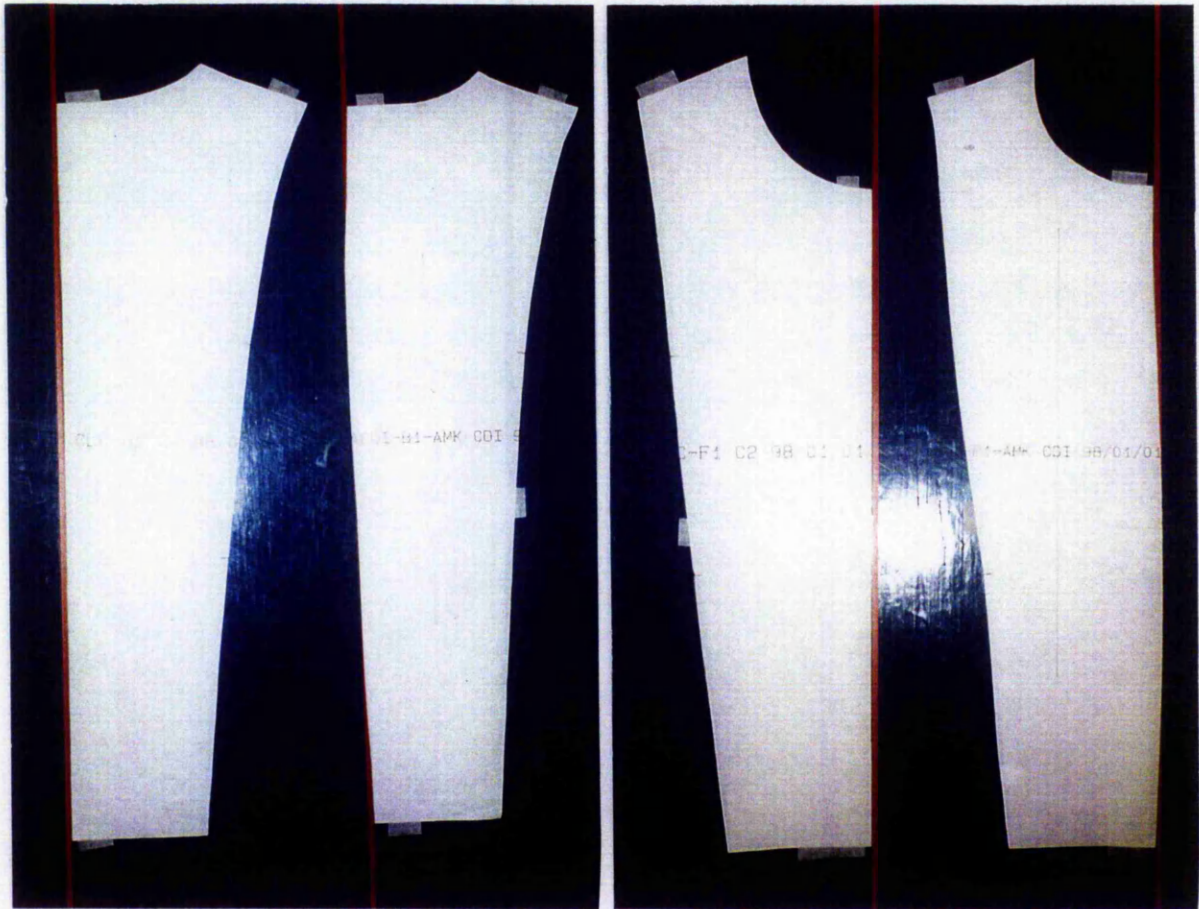
(manually toiled) Sample 20-C = CBACK + SBACK + SFRONT + CFRONT
The red figures are the measurements for 3D patterns; the black figures are for 2D patterns.

Figure 5.34 The tension and compression analysis for the CDI-3D 'Standard' flattened patterns [5.4.A]



The above four patterns of Sample 19 (CDI-3D 'Standard' flattened) showed their individually flattened tension and compression, but in general, the CBACK, SBACK, and SFRONT were about 5 %, the CFRONT's were less than 3 %.

Figure 5.35 The centre front and centre back comparison between the CDI-3D 'Standard' flattened and manually toiled patterns [5.4.A]



Left: CBACK of Sample 20-C
(manually flattened pattern)
Right: CBACK of Sample 19-P
(CDI 'Standard' flattened pattern)

Left: CFRONT of Sample 20-C
(manually flattened pattern)
Right: CFRONT of Sample 19-P
(CDI 'Standard' flattened pattern)

Third, Sample 19-C had obvious difficulties when dressed on the real sample garment form due to the shortened front and back neck girths. The shoulder line was inconsistent between the front and back shoulders (Figure 5.36). The back armseye of Sample 19-C was elongated, and the two front and back seams were more consistent with the 3D pattern, but the waist line was less smooth than Sample 20-C (see Figure 5.36). This showed that, the minimisation of the electronic pattern distortion by which pattern edge measurements were changed correspondingly did not provide a radical improvement for the 3D-PDS.

Finally, although the basic close fitting block used 2-seam construction and is widely used in the garment industry, during the manually toiling process, it was found that the 2-seam pattern construction for the FRONT and BACK patterns could not produce 'contact-fit' patterns for the real sample garment form. In the areas of the two convex measurements areas (i.e. the shoulder blade, the bust seam areas) and the back neck area¹¹. Despite these deficiencies, the manually toiled foundation patterns still provided a better contact-fit and seam accuracy than that of the CDI-3D 'Standard' flattened patterns (see Figures 5.36-37). This reinforced the second point made above that the parameters for a reasonable range of pattern distortion and for the discrepancy tolerances of the pattern edge measurements would need to be found. These two major issues need to be taken into account together because matching only pattern edge measurements or areas between 3D and 2D patterns, in theory or in practice, would not produce a good quality of 'contact-fit' pattern.

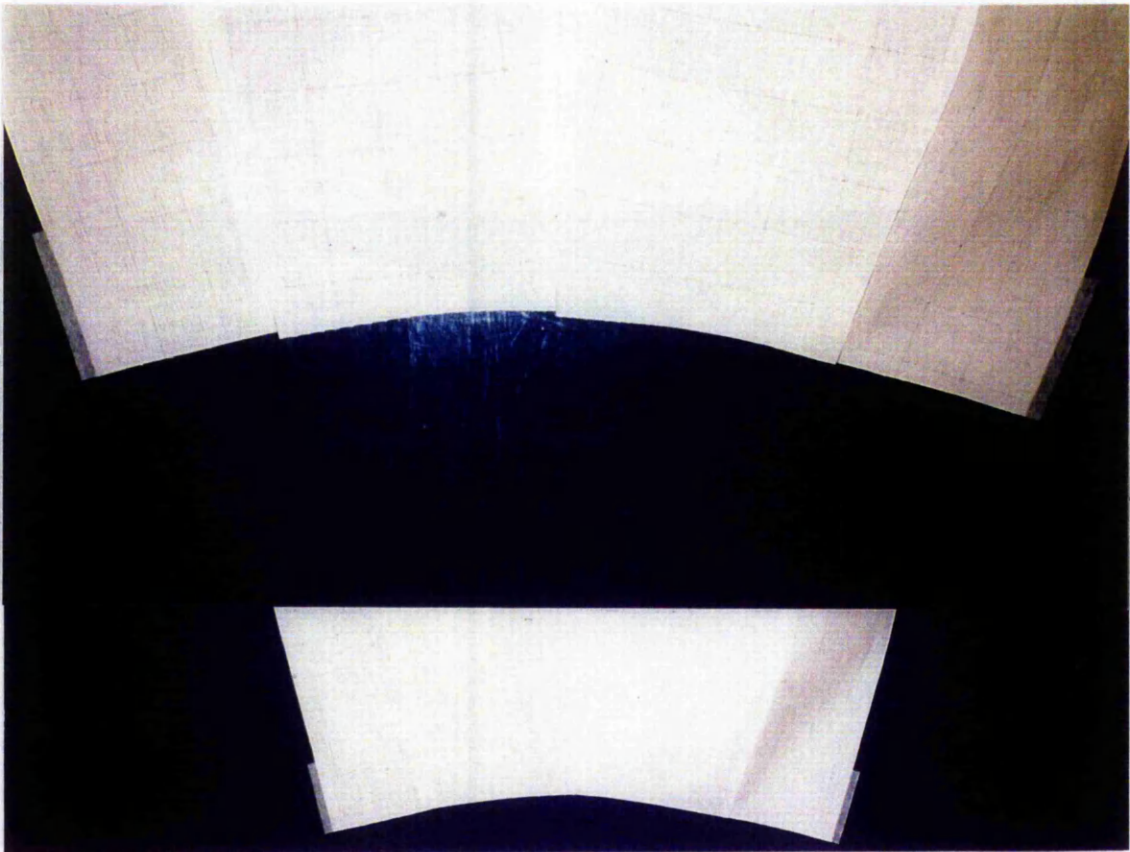
¹¹ The deficiency caused at the back neck area can be avoided by shaping centre back (see section 4.5.2).

Figure 5.36 The comparison of the waist and shoulder lines between the CDI-3D 'Standard' flattened and manually flattened Samples [5.4.A]



Left: (manually flattened) Sample 20-C

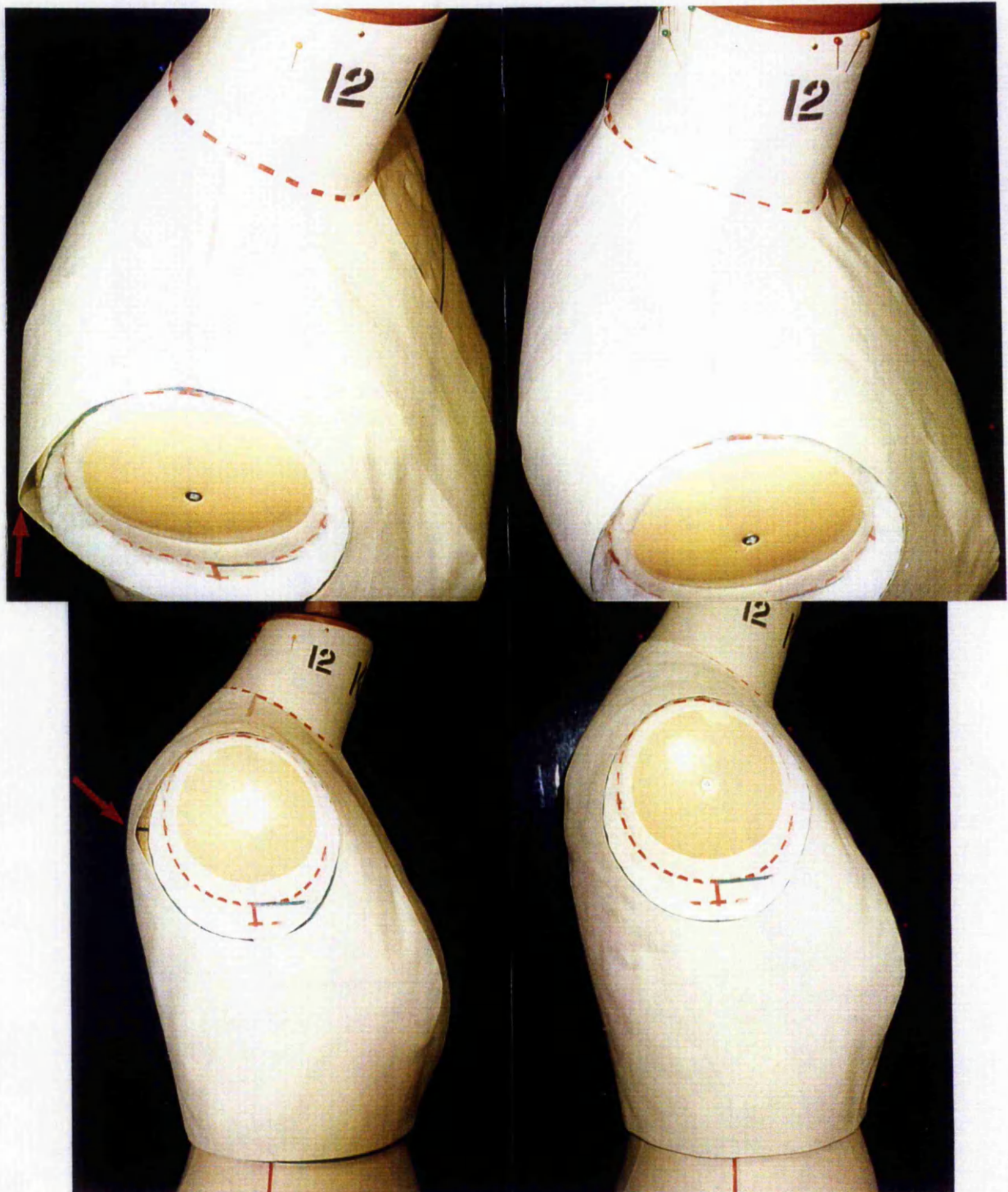
Right: (CDI 'Standard' flattened) Sample 19-C
The shoulder line was with a gap.



Top: (CDI-3D 'Standard' flattened) Sample 19-C
The waist line was not a smooth curve line.

Bottom: (manually flattened) Sample 20-C

Figure 5.37 The manually toiled patterns were not *contact-fit* in the back neck, front, and back convex measurements areas [5.4.A]



Left top and bottom pictures:
(CDI-3D 'Standard' flattened) Sample 19-C

Right top and bottom pictures:
(manually flattened) Sample 20-C

Experiment 5.4.B 'Edge-matched' with 'Standard' flattened patterns and with manual patterns

The 'Edge-match' flattening process could keep pattern edges consistent for 3D and 2D by increasing or decreasing stress and strain within the pattern. By doing this, pattern area would be increased or decreased correspondingly in order to keep all the pattern edge measurements identical between 3D and 2D.

Purpose

This is to examine whether the 'Edge-matched' pattern flattening could provide a more accurate pattern in comparison with the 'Standard' flattened patterns and manual patterns.

Processes

The processes of this type of flattening were the same as in previous experiments, except that the 2D pattern edge was pre-defined when flattening a 3D pattern. The flattened four patterns created Sample 21 (Figure 5.38) which was cut out as Sample 21-P (paper).

Outcome and analysis

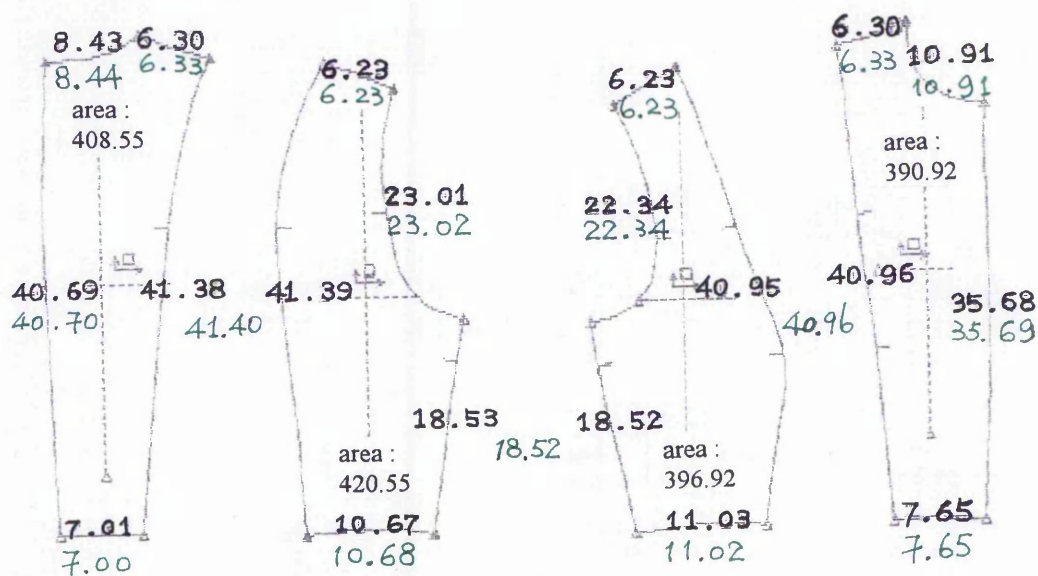
The first comparison was made for the 'Edge-matched' flattened Sample 21 (see Figure 5.38-39) with the 'Standard' flattened Sample 19 [5.4.A] (see Figure 5.33).

First, comparing the CFRONT of the Sample 21 to the Sample 19 [5.4.A] (see Figure 5.38), the neck girth and shoulder length were enlarged, the centre front was shortened by about 1.8 mm, but both pattern areas only differed by 0.5 square centimetres.

Second, comparing the SFRONT of Sample 21 to the Sample 19 [5.4.A], the front seam length was shortened by 5.4 mm and the front armseye girth was shortened by 2.3 mm. The pattern area was reduced by 5.76 from an original 402.68 square centimetres.

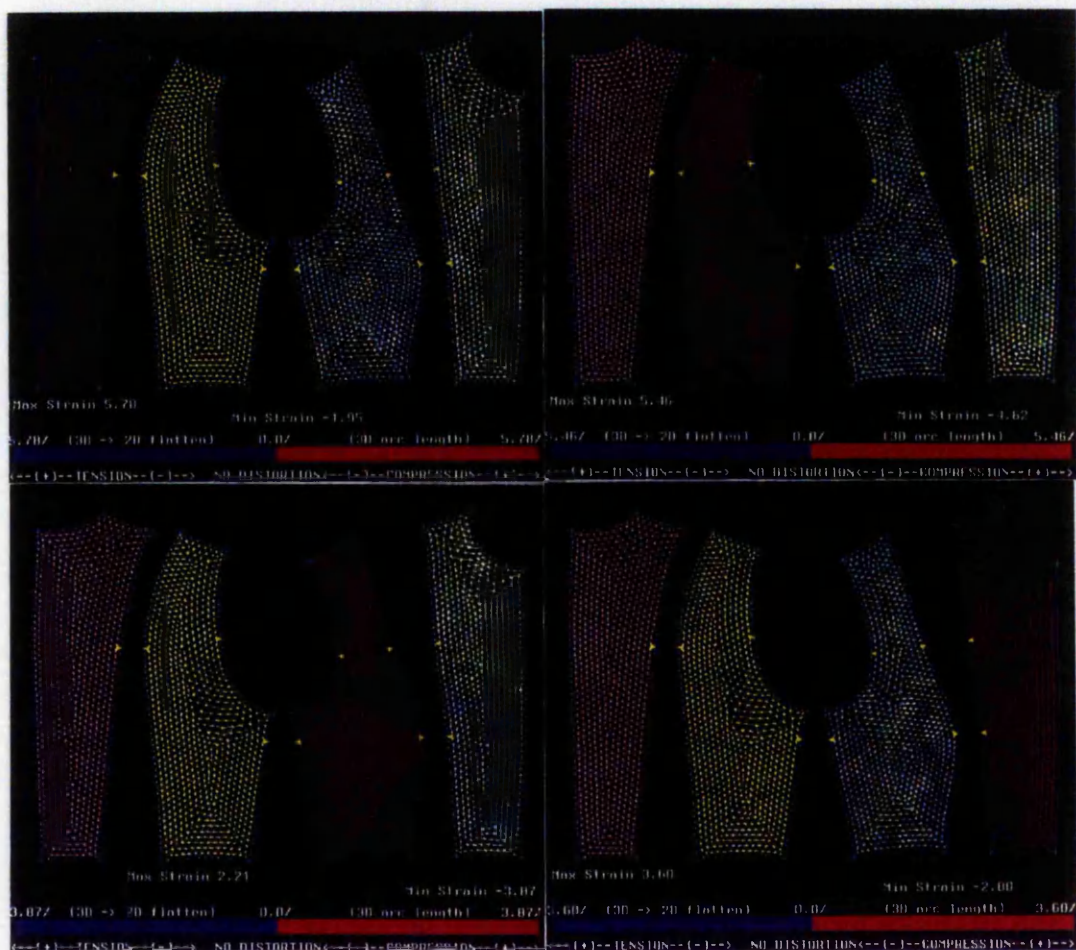
Third, comparing the CBACK of Sample 21 to Sample 19 [5.4.A], the back neck girth, shoulder length, and the back seam were all enlarged. The pattern area was also enlarged correspondingly. This was caused by the flattening tension increasing to 3.2 % (see Figures 5.34 and 5.38).

Figure 5.38 The strain analysis of the four 'Edge-matched' patterns [5.4.B]



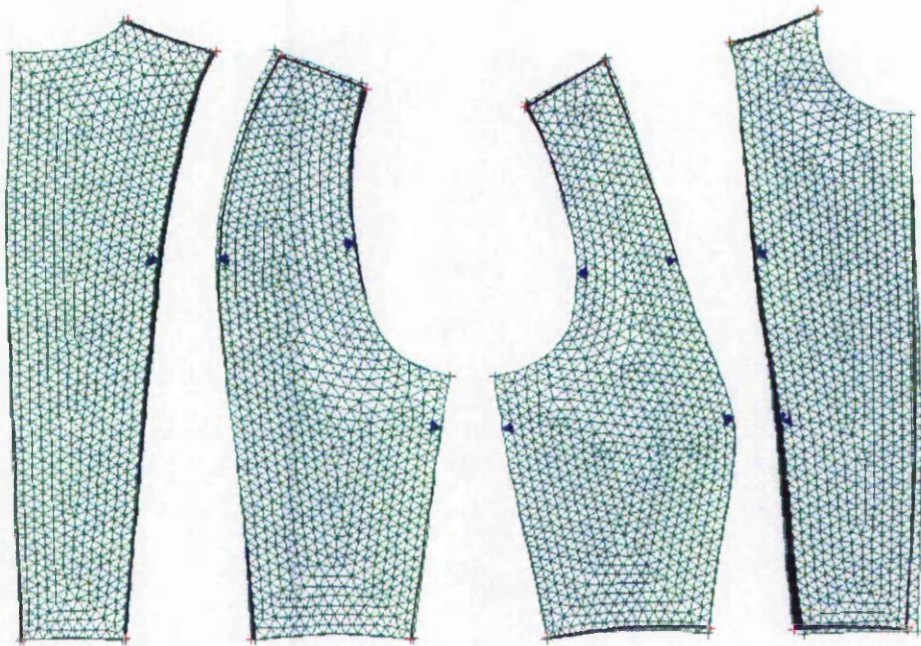
(The 'Edge-matched' flattened) Sample 21

The green figures are the measurements for 3D pattern; the black figures are for 2S pattern.



Although the four 3D patterns of Sample 21 ('Edge-matched' flattened) were flattened to 2D patterns with almost identical pattern edges (above), it caused more tension in CBACK and CFRONT and more compression in SBACK and SFRONT than that of Sample 19 (see Figure 5.34).

Figure 5.39 The comparison between the manually toiled patterns and the 'Edge-matched' flattened patterns [5.4.B]



The patterns in solid black were Sample 21('Edge-matched' flattened), the patterns in green meshes were Sample 19 ('Standard' flattened).

The pattern areas of SFRONT and SBACK of Sample 21 were decreased than that of Sample 19, but CBACK's was increased and CFRONT's was almost identical. This change corresponded to the change of the tension and compression (see Figure 5.38).

The more the tension, the more the pattern areas; but, the more the compression, the less the pattern area.

Finally, comparing the SBACK of Samples 21 and 19 [5.4.A], the back armscye, shoulder length, and back seam were shortened, but the side seam was increased. This inevitably reduced the pattern area because of the higher compression (see Figures 5.34 and 5.38).

The second comparison was made for the 'Edge-matched' flattened Sample 21 (see Figure 5.38) with the manually toiled Sample 20 (see Figure 5.34).

Comparing the CFRONT of Sample 21 to Sample 20 [5.4.A], only the front seam lengths had a 2.9 mm inconsistency with each other, and the seam construction shape of Sample 21 was less smooth than that of Sample 20, but the pattern area was reduced by 6.5 square centimetres.

Comparing SFRONT of Sample 21 to Sample 20 [5.4.A], all the pattern edges of Sample 21 were closer to the pattern edges on the 3D sample garment form than that of Sample 20, but the pattern area was reduced by about 7.6 square centimetres.

Comparing CBACK of Sample 21 to Sample 20 [5.4.A], all the pattern edges were closer to the 3D pattern on the 3D sample garment form than that of Sample 20, but the pattern area was also increased by about 3.6 square centimetres

Comparing SBACK of Sample 21 to SBACK 20 [5.4.A], all the pattern edges of Sample 21 were closer to the 3D pattern edges on the 3D sample garment form than that of Sample 20, but the pattern area was reduced approximately 3.2 square centimetres.

From the comparisons made above, it is demonstrated that the minimisation of the electronic pattern distortion was achieved by changing either pattern area or edge measurements. This electronically automatic adjustment to the pattern did not solve the problem of obtaining a 'contact fit' pattern because the edge-matched pattern caused the problem of obtaining a stable pattern shape. Therefore, it was seen as important that a future 3D-PDS needs to provide the parameters for an acceptable range of electronic pattern distortion and the discrepancy tolerance of pattern edge measurements. An example, using a foundation pattern construction, may be needed to demonstrate this.

Discussion

The pattern edge measurements of the 'Edge-matched' flattened patterns were almost identical to the measurements on the 3D sample garment form. They were much closer than those of 'Standard' and manually flattened patterns. However, the pattern areas varied; some were almost identical, some increased or decreased (see experiment 5.4.B). At this stage, the garment pattern designer has no means of controlling these variations.

The changes of tension and compression of the flattened patterns, which affect pattern shapes, were also changed to correspond with the changes of the pattern areas and edge measurements. These differences or changes create further uncertainty for garment pattern designers. The pattern shape changes are only apparent after the 3D pattern is flattened. Once again they are implications which have occurred by neglecting the needs of the pattern design process.

Up to this stage, it was found that patterns electronically flattened (i.e. 'Standard' or 'Edge-matched' flattening) could not provide 2D patterns as satisfactorily as patterns produced by the manual method. Importantly, in the manually flattened patterns (i.e. Sample 20-C), almost all pattern edges were consistent to the measurements of the sample garment form, except the front and back seam areas (see Figure 5.37). This latter problem of matching curved seams, which occurs in both real and virtual worlds, is an essential concern to be addressed for 3D-PDS.

Despite all of the problems identified, it was thought it could be possible that electronic pattern flattening could obtain 'contact-fit' as satisfactorily as manually toiled patterns if enough seams were constructed which passed through the appropriate dual bending areas. Although it is also acknowledged that a target of mass production pattern cutting is to reduce the number of seams, it would be necessary to investigate an appropriate seam number when attempting to establish a good quality 'contact-fit' pattern for use as a *standard* 3D 'block' for assisting in checking modified patterns. The next two experiments were designed to examine this issue.

5.5 Verification Experiments

Background to the experiments

The knowledge gained in experiments 5.4.A~B showed that one more cut, at least, would be needed in an appropriate dual bending area to improve the problems of the two measurements which existed in Sample 19 [5.4.A]. Hence, two further experiments were designed to examine first, the front and back neck girths which were comparatively shortened than when they were in the 3D patterns and second, the front and back seam lengths which were elongated and compressed because there was still one bending curvature formed at SFRONT and SBACK (Figure 5.40).

Through the knowledge gained from the manual toiling process, it was also realised that a small amount of ease existed in the back neck area in Sample 20-C (see Figure 5.37). The front and back seams on the 3D sample garment form were slightly longer than on the 2D foundation patterns. From Sample 20-C (i.e. manually toiled patterns), the grain lines were initially controlled, by visual judgement, along each 3D pattern centre. After being toiled, the grain line provided a guide for a stabilised pattern shape, as stated in the beginning of section 5.4. This provided the grain reference for the electronically flattened patterns.

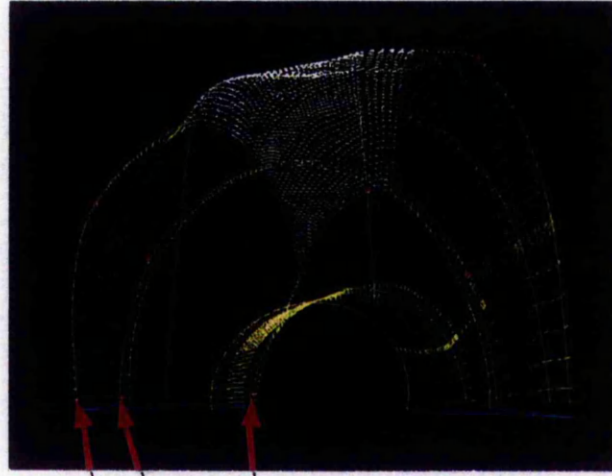
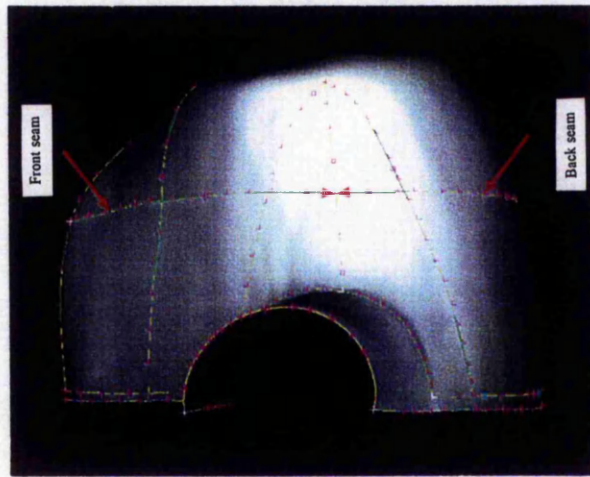
Having considered these practical conditions, it was decided that one more cutting line for SFRONT and SBACK could be placed as Sample 22 (see experiment 5.5.A). Further application was placed as Sample 23 (see experiment 5.5.B). The two experiments were as follows:

Experiment 5.5.A **Pattern flattening with an extra seam control**

Experiment 5.5.B **Pattern flattening with further seam control**

Figure 5.40 The front and back side bodice with a bending curvature [5.5.A]

The top view of an half upper bodice garment form



Left:
The garment form with a 'Shading' technique (see Appendix 18). After placing the front and back seams, the SFRONT and SBACK patterns still retained obvious dual bending curvatures.

Right:
The garment form without a 'Shading' technique. The three half elliptical curves are the neck, waist, and bust girths.

Experiment 5.5.A Pattern flattening with an extra seam control

In Figure 5.40, it was apparent that the SFRONT and SBACK were bent more than the CFRONT and CBACK. In consideration to the distortion caused in a spherical surface (see experiments 5.3.2.A~C), it was seen that the bending characteristics in the SFRONT and SBACK needed to be reduced in order to obtain a better contact-fit pattern.

Purpose

To verify the possibility of obtaining more accurate 2D patterns by adding one more seam to flatten the incomplete flattened bending area which appeared at the SFRONT and SBACK.

Processes

An extra seam was constructed to cut SFRONT and SBACK of Sample 19 [5.4.A] with reference to the grain direction of Sample 20-C [5.4.A] in the real world. Four pattern pieces were created as Sample 22 (Figure 5.41).

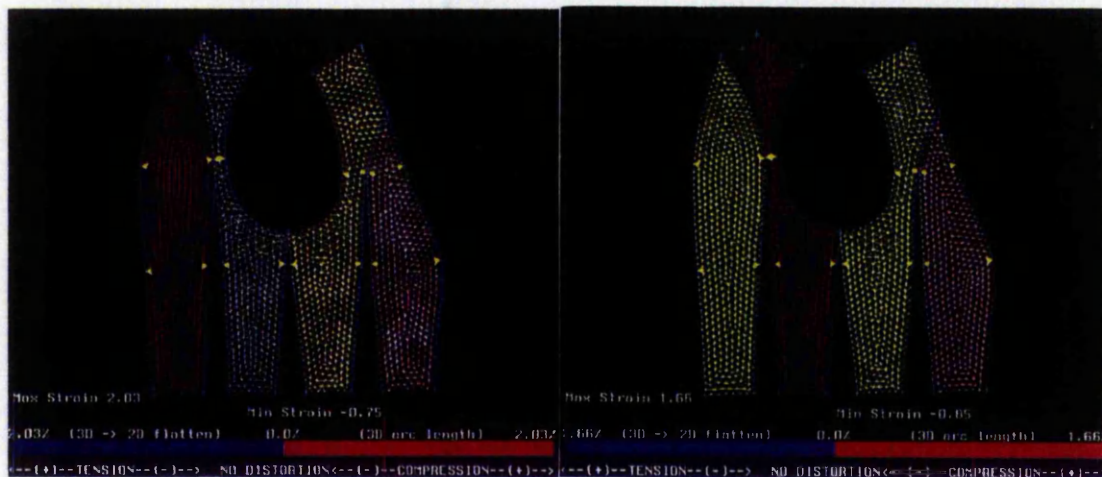
Outcome and analysis

Comparing Sample 22 to the 'Standard' flattened Sample 19 (see Figure 5.34), it was found that the tension and compression were reduced. The back seam area also appeared to have a better contact-fit because a further opened area was produced.

The armscye area which was formed by SFRONT 2 and SBACK 2 of Sample 22 fitted the armscye of the 3D sample garment form with a better contact-fit than the one formed when the SFRONT and SBACK of Sample 19 [5.4.A] was assembled.

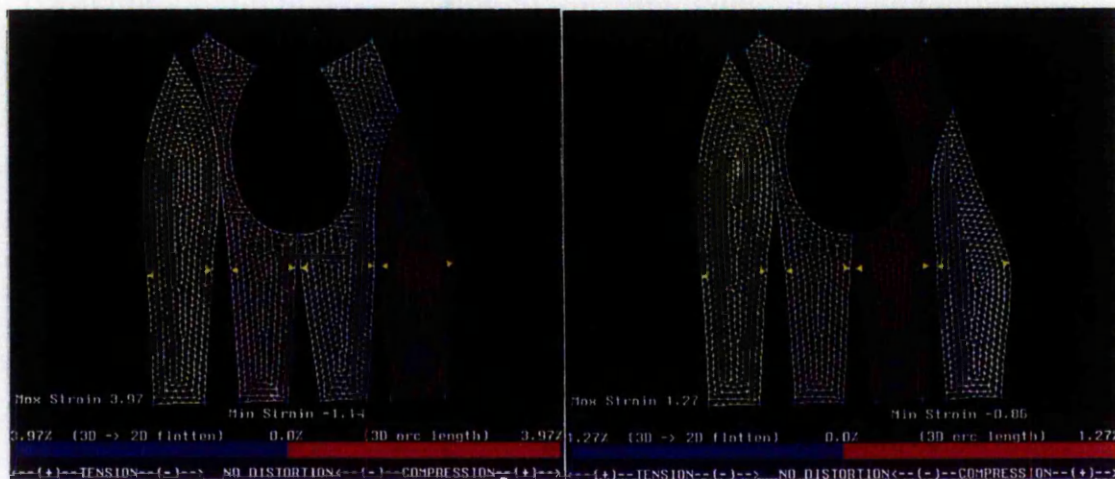
The back seam was located too close to the back armscye area, it caused a slightly pronounced form when being assembled using plotted paper pattern. This experiment implied that electronic pattern accuracy could be controlled with a better quality of 'contact-fit' pattern if the significant dual bending curvature area could be found and flattened using one more seam.

Figure 5.41 The new seams were constructed to flatten the side front and back bodice pattern [5.5.A]



SBACK 1 of Sample 22

SBACK 2 of Sample 22



SFRONT 2 of Sample 22

SFRONT 1 of Sample 22

Experiment 5.5.B Pattern flattening with further seam control

Purpose

To modify the insufficient front and back neck girths of Sample 19 [5.4.A] and to improve the placement of the extra seam in the previous experiment 5.5.A.

Processes

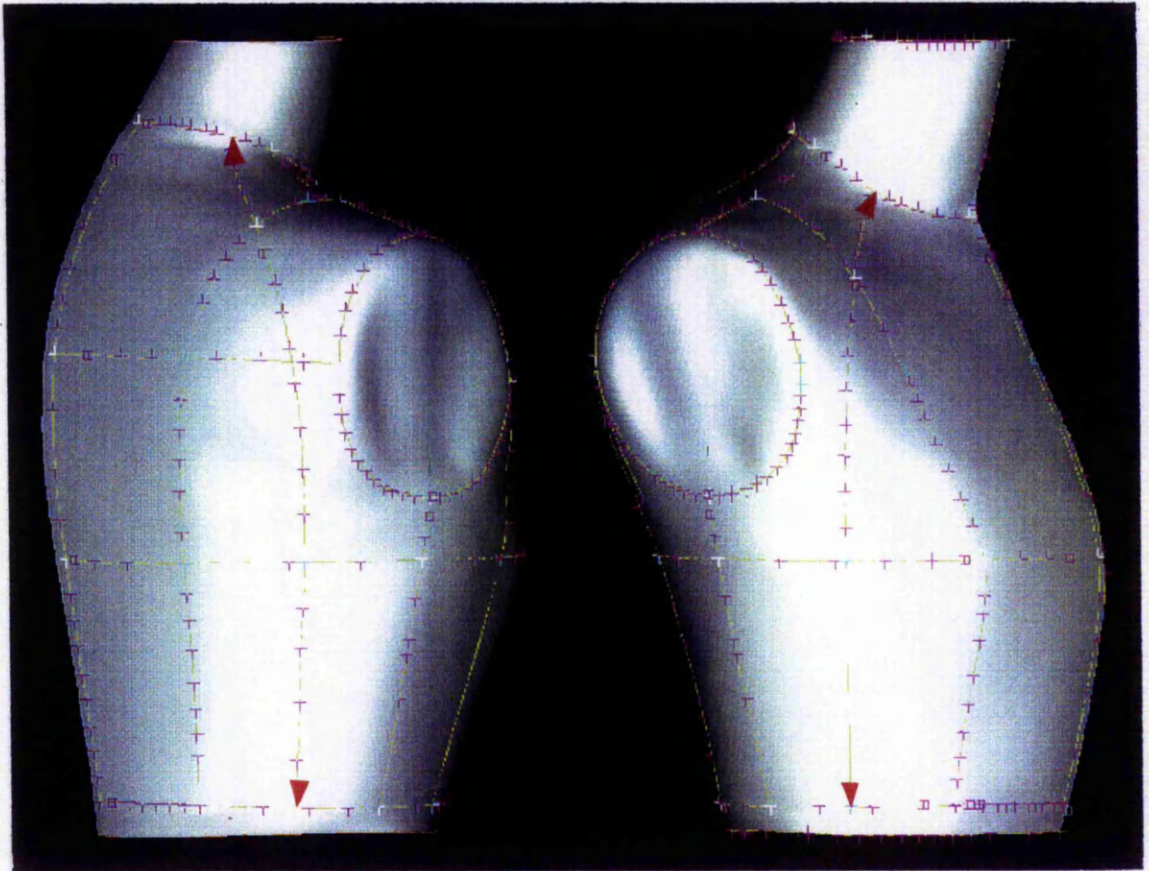
The current CDI-3D system, prior to flattening a 3D pattern, did not provide a standard procedure for identifying a grain line on the 3D sample garment form. An alternative method was devised as follows.

- (1) The created 3D sample garment form which was used to produce Sample 19 (see experiment 5.4.A) was prepared for this experiment.
- (2) A 3D vertical line approximately crossing over the centre of the SBACK to the mid back neck girth of CBACK (Figure 5.42) was constructed on the created 3D sample garment form with the four identified foundation patterns (of Sample 19). The 'XYZ Curve'¹² was used for this line construction.
- (3) This newly constructed 3D vertical line was converted and projected onto the sample garment form as a seam through the 'Translator' program¹³. This new cutting line divided CBACK and SBACK (of Sample 19 [5.4.A]) to four pattern pieces as the BACK of Sample 23 (Figure 5.43).
- (4) The same method was applied to CFRONT and SFRONT of Sample 19 [5.4.A]. This created four patterns as the FRONT of Sample 23 (see Figure 5.42-43).

¹² In the CDI-3D system, the 'XYZ Curve' is one type of curve which is constructed only in space (i.e. in three dimensions). It cannot be used to identify any style line on any generated form 'Surface', e.g. the sample garment form surface.

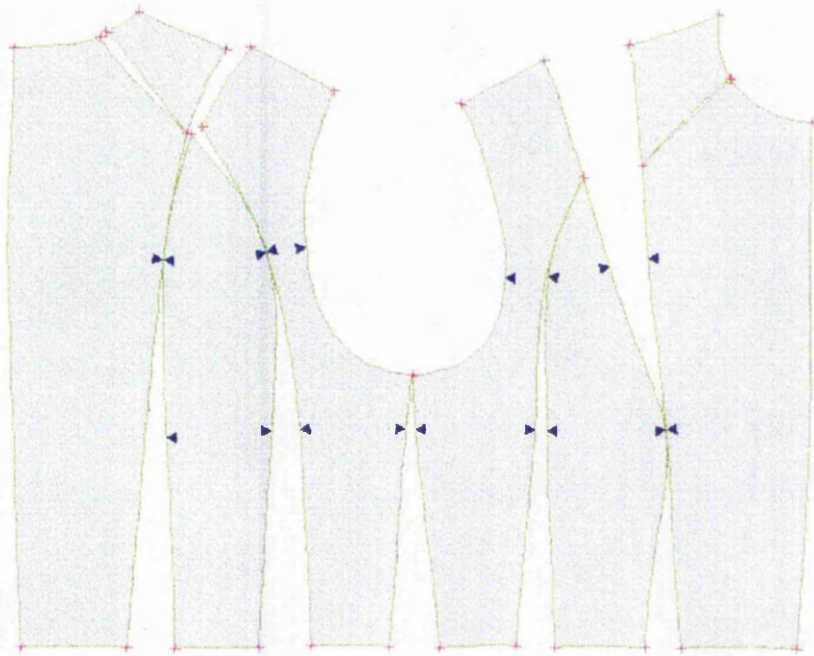
¹³ In the CDI-3D system, the 'Translator' program was developed to change the 'Curves' characteristics for different uses. In this example, the constructed 'XYZ Curve' needed to be changed to a 'UV Curve' in order that style design lines could be attached on the sample garment form surface (see section 3.4.4.2, pp.3-64 ~ 65).

Figure 5.42 The placement of the new cutting lines on the front and back side bodice patterns by reference to the grain direction of the four manually toiled foundation patterns [5.5.A]



Two new seams were constructed respectively at the Back and Front garment forms.

Figure 5.43 Pattern flattening with further seam control [5.5.A]



Sample 23 = CBACK 1-2 + SBACK 1-2 + SFRONT 1-2 + CFRONT 1-2

Outcome and analysis

In terms of the accuracy of the pattern edge measurements, both front and back neck girths showed improvement; however, having assembled the front and back patterns, it was still difficult to dress the front neck girth on the sample garment form.

Also, when the eight patterns of Sample 23 were assembled and dressed on the real sample garment form, the foundation patterns were shown to be in a better contact-fit than Sample 19, despite the problem caused at the side front neck girth area (this is discussed in the next section). Although the back seam was moved inward from the previous back seam position (see experiment 5.5.A), a slightly pronounced form still remained because the removed position was not close to the blade area.

The experimental result provided a very convincing example that the current 3D-PDS may not be sufficient for use in obtaining garment patterns which could be ready for final production use, but it did produce a *reasonable* flattened pattern to which improvements could be made further.

Discussion

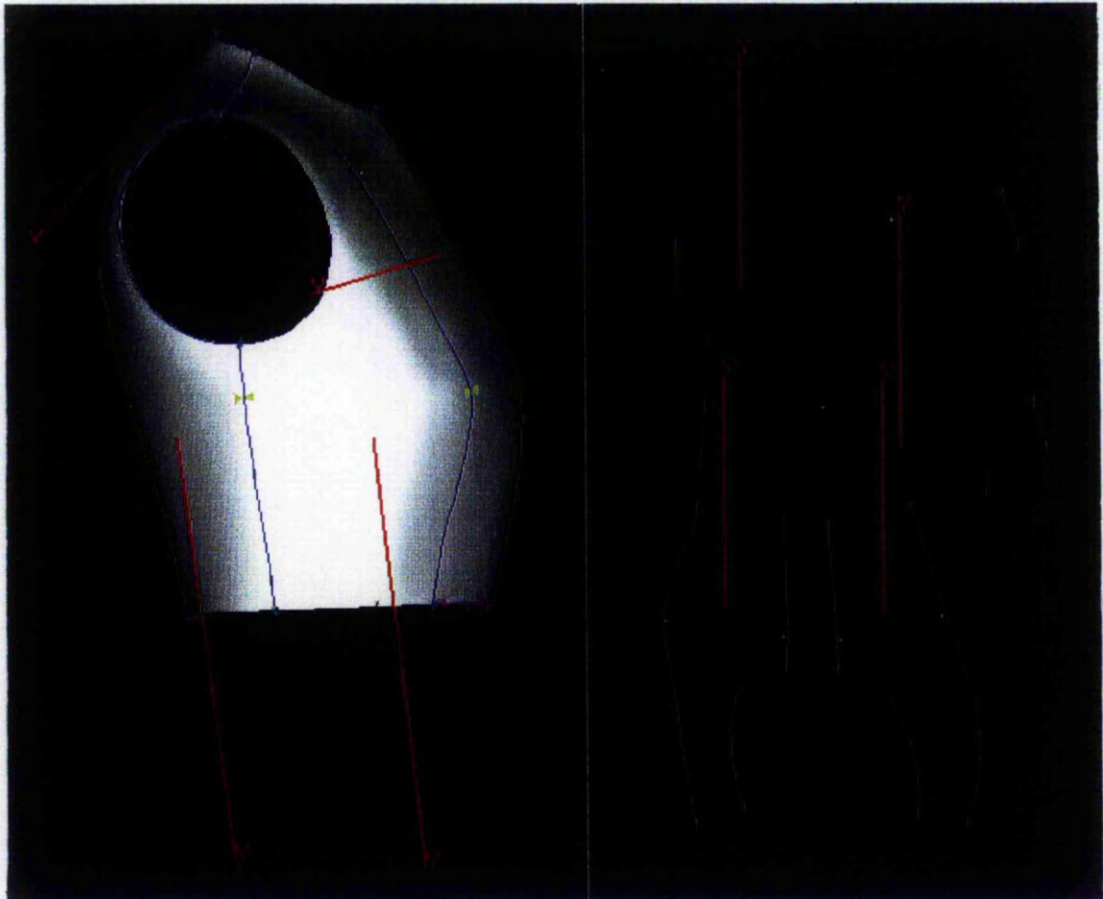
These two verification experiments showed that, in order to obtain a contact-fit pattern using electronic pattern flattening, three main conditions needed to be addressed.

First, the requirement of placing a grain line should not be just for use in the 2D 'pattern' condition, it is an important guideline for a garment pattern designer when developing new styles through the construction of different garment pattern shapes on the garment form. This requirement is not available until a pattern is developed (Figure 5.44). However, the grain line is a useful guide not only for a technical pattern cutter to develop patterns, but also important for a garment designer when she/he is developing a garment style.

Second, pattern accuracy and pattern shape stability could be kept at a reasonably consistent level when the 3D garment pattern was flattened with a minimum of 6 cutting lines which were created as 8 seams. It may be possible to reduce these seam numbers if the 'discrepancy tolerance' of the pattern edge measurement between 3D and 2D could be specified. However, seam placements would still have to be constructed to pass directly through the prominent dual bending areas. The front and back necklines (see experiment 5.5.B) are examples which express this condition. This is a significant constraint for designing a garment pattern. It is necessary to overcome this limitation so that a designer can have a secure base to feel confident when developing a design idea.

Finally, pattern validity is an essential process both in the manual and electronic methods of garment pattern cutting. The validating process needs to consider both 3D and 2D garment pattern conditions. This means that pattern modification needs to be undertaken both in 3D and 2D patterns. To achieve this, the minimum electronic pattern distortion needs to be defined; the specifications of the 'discrepancy tolerance' of pattern edge measurements between 3D and 2D need be established using garment pattern conditions and this will be addressed in the next chapter.

Figure 5.44 The function for grain line in the current CDI-3D system



In the current CDI-3D system, the function of grain line is not available until a pattern is developed.

5.6 Discussion

These experimental results demonstrated the importance of devising a process (see Chapter Four) by which stable comparisons could be made between pattern cutting in the real and virtual worlds, so that some 'verifiable' knowledge of the electronic 3D to 2D flattening process for garment pattern use could be obtained. The specific limitations and potential of the current CDI 3D-PDS are investigated in two main strands: the 3D pattern design and flattening process and the system functions.

THE 3D PATTERN DESIGN AND FLATTENING PROCESS

Limitations

The 'Keymarks' and 'Grain' functions, in the CDI-3D system, were not available in the 3D garment form surface (see 'Background to the experiments' in section 5.2). It has to be acknowledged that both landmarks and grain lines are needed in a 2D garment pattern stage for technical requirements. However, they are equally important for a garment designer in both the real and virtual worlds in the development of the style on the 3D garment stand and garment form.

The use of the garment *dart* was not available in the current CDI-3D system (see experiments 5.3.1.A~B and 5.3.1.E). It was found that using a curve or style line (e.g. the UV curve, see experiment 5.3.1.A) to cut the bodice FRONT pattern did not conform to the use of the garment dart which is commonly used in the manual pattern cutting. Yet, when the dart suppression was transferred to a seam which was not located in a significant dual bending area (see experiment 5.3.2.B), the two adjacent pattern edges were different lengths and shapes because each 3D pattern piece often had a different bending curvature.

Another limitation is that pattern shape modification and validation cannot take place when a 3D pattern is developed. For example, when a style line is moved, the flattened pattern shape does not change correspondingly. Instead, the designer needs to re-locate

the style line and re-flatten it, which means that pattern distortion and pattern shape stability is changed and not yet predictable. The process of constructing style lines in the generated 3D garment form 'Surface' was very difficult to control. In attempting to control an acceptable style line, a designer's original design concept would possibly become distorted.

Finally, the process of controlling a 3D garment form surface also took tremendous effort. This was particularly true when the attempt was made to control a virtual garment form to be identical to the one in the real world. If this limitation cannot be explored, from a designer's viewpoint, the use of a 3D-PDS in the garment industry is seen unlikely to be possible.

Potential advantages

One of the best features provided by the CDI-3D system was that it allowed a designer to construct garment style lines through an 'un-interrupted' design process, i.e. the rotation of the 3D garment form could be controlled from any angles. This function strengthened the ability of a traditional garment designer's 2D design sketching to take place in three dimensions.

The 'real-time' mesh generation and flattening for a pattern gears and elevates the motivating process of cutting a garment pattern. Importantly, through these generated meshes (i.e. 'Regions') both in 3D and 2D patterns, the electronic pattern could be modified. The modification was held only in the 'Region', itself. Although the pattern shape would change correspondingly, efforts are still needed to improve it if it is to be used as a final production pattern.

The stress and strain analysis is a brand-new discipline for a garment designer to cope with. Initially, they appeared to be an interruption rather than an assistance for a designer to 'acknowledge' the electronic pattern distortion. However, it is the fundamental technology of the system that a designer would have to accommodate as computerisation could not simulate exactly the same work process as in the real world. If a designer could master this process, it was seen possible that a 'contact-fit' pattern could be obtained.

THE SYSTEM FUNCTIONS

Limitations

Sizes and measurements are the two most fundamental requirements for a garment pattern cutter to draft patterns in accordance with a garment designer's 2D design sketches. They were not available in the current CDI-3D system. This resulted in a computer generated garment form with a realistic visualisation only. The main reason for this was that the 'Keymarks' function was available only when a specified area was developed as a pattern. Clearly, sizes and measurements are not just used for pattern construction, they are also needed for representing an individually regarded 'standard' body form.

A significant limitation was the lack of an effective method of processing a '3D garment prototype' together with control measurements and fit specifications. This deficiency not only slowed down the whole garment design process, but made impossible the maintenance of seasonal block collections for each individual company. Another limitation was that '2D design sketching' function was not devised interactively in the current 3D pattern design process. If a 3D-PDS is attempting to carry out garment design and pattern cutting in three dimensions, the '2D design sketch' is seen as comparatively important for the user. This is because the majority of the users may be garment designers who are often inspired by means of 2D sketching. This requirement needs to be active even when 3D garment design process is in progress, so that the garment designer can re-call or re-fresh an idea whenever it is needed.

Finally, the system warnings and memory availability were insufficient in the current CDI-3D system. Although there were some occasions when the system warned of this and suggested a change of parameters automatically, on many occasions, the system crashed without warning and important data were lost. The CDI-3D system used in this study had 128 MB memory, whereas 35 MB memory was used in order to run the 3D software, itself. The experience gained showed that the ideal memory for running 3D-PDS software would need more available memories. Both Shah (CDI-3D software programmer) and Finnegan (CDI-3D manual writer) pointed out that the CDI-3D system requires 35 MB to run the software (see pp.6-14~15). They also pointed that, for a user who constantly uses

the 'Regions' flattening program, it is ideal to have, at least, 256 MB of computer memory and 512 MB swap space. However, this recommendation of an effective computer memory capacity for 3D-PDS use does not mean that a system can work perfectly for garment designers and pattern cutters. The practical limitations of irregular electronic pattern shapes still remain.

Potential advantages

The current CDI-3D system has developed a specific function which could interpret and minimise thousands of digitised 3D data to visualise a 3D garment stand or agreement form surface. This platform may have potential to be developed in conjunction with the existing 3D digitising technologies. This connection, i.e. linking 3D digitising techniques available and 3D-PDS, may be able to eliminate, or at least reduce, the time consuming process of generating a 3D garment form when 3D digitised data were obtained.

Another advantage which the CDI-3D provided was its linkage with a standard industrial 2D-PDS, GGT AccuMark system. This enabled electronically flattened patterns to be plotted and checked in full size. Through an ethernet network, the flattened 2D pattern was imported into the linked AccuMark. Further modification could then be made using the 2D pattern design program in the AccuMark system. Currently, the AccuMark file can also be exported into the CDI-3D system through a certain file converting process. However, modification to the file is required.

Finally, CDI has developed a '2D concept design system', i.e. namely 'U4ia' software, which allows the developed garment style to be represented together with the fabric required. Therefore, the designed image can be visualised realistically. This may be able to shorten the garment design cycle in the future.

The analysis above provided a secure base for this study to propose improvements and further investigations for a future 3D-PDS for garments. This is discussed in the next Chapter. This will contain five main sections: first, an introductory section for the chapter; second, analysis of the current situation (the collections of the previous research); third, based upon the distilled knowledge, to identify the potential stages of the

development of the 3D-PDS; fourth, focusing and identifying the basic requirements for the first stage of a 3D-PDS; finally, proposing the potential system structure for the most fundamental stage of a future 3D-PDS.

6 3D-PDS IN THE GARMENT ENVIRONMENT

6.1 Introduction

The use of '2D blocks' is the major method of pattern development adopted by the clothing industry. The advantage of this methodological approach to manual pattern cutting offers the control of the shape of patterns and sizes. Clearly, the success of a 3D-PDS would offer, at least, the approval of a 2D block for production use. The experimental results, gained in Chapter Five, showed that current leading 3D-PDS could produce a garment pattern with a reasonable geometric shape if the cutting lines were constructed through the precise dual bending areas (see p.6-12). However, its viability for use as a production pattern requires further pattern modification and validation.

These problems were addressed, for the very first time, using practical examples (see sections 3.4.3 and 3.5). This study also provided the first objective method of comparing and analysing electronically flattened patterns in juxtaposition with manually flattened patterns in contrast to other researchers in this field. This is because it required different disciplinary knowledge, from other researchers in this field who are mainly from computer science. This study solved important issues by providing an investigation process and by clarifying the diverse combinations of techniques embedded in manual pattern construction. More importantly, the foundation knowledge of a 3D-PDS was interpreted from the point of view of garment design and pattern cutting so that the practical problems were addressed fully in a garment environment. From published papers researched (see section 3.5), this study can be regarded as the first material to examine 3D technology using the perspective of manual garment cutting.

As garment manufacturers operate the design to product process in the ways which are relevant to their size and type of product, this approach also copes with the demands of supplying niche markets which require different types of garment fit. A problematic use of the term fit was solved by an explanation of 'fit' (see Figure 2.15, p.2-56) and a fit

coding model which clarified the use of the term 'fit'. This was constructed to build an effective communication between garment design and pattern cutting, particularly when these two jobs are separated. 2D-PDS has also resulted in the two processes, styling and technical design, being made more separated (see section 3.1, p.3-3). 3D-PDS was seen as an attempt to pull these two processes together in order to solve ineffective communication problems (London, 1998).

This study was derived from a concept that these two work processes should be integrated together (see section 1.1). At present this argument is still controversial. However, modern 3D pattern technology showed the opportunity for this concept to be realised. But, with the diverse variables, e.g. garment close fitting forms and fabrics, embedded in manual garment pattern construction, this modern technology is bound to be frozen if the value of manual garment pattern cutting expertise is not recognised. Those skilful techniques of making garments are often underestimated (see Staples in Kalman, 1997). Importantly, benefits can be brought for both garment and modern technology industries, only if software developers can make technological innovations for the garment industry with the real participation of their practical users (i.e. garment designers and pattern cutters), and this needs to be in the early investigating stage of the development.

3D-PDS has attempted to create a means of control for a designer to develop an idea from a sketch design to final production patterns. Crucially, it was realised that there was a need to create a bridge for mutual communication between the two disciplines of 3D pattern technology (i.e. software developers) and the garment industry (particularly garment designers and pattern cutters). This bridge would enable potential applications and problems to be addressed, in practice. Hence, further improvements could be made by means of this mutual understanding.

To make this possible, an understanding of the basic knowledge of both disciplines involved in the process is required. In this context, two major areas had to be investigated; these are: the fundamental requirements of cutting mass garments and 2D/3D digitising and pattern technologies. This study has identified the limitations of the current 3D-PDS using manual pattern cutting expertise (see sections 5.2.3, 5.3.3, and 5.6)

and has taken full advantage of the existing garment CAD software available by means of linking 2D/3D PDS (see section 4.6) so that electronically flattened patterns can be visualised in a full scale through an output device, e.g. printer or plotter.

From a designer's viewpoint, garment design and pattern cutting processes consist of many interacting factors, and 3D pattern technology is brand new knowledge for a designer or cutter to learn. In order to understand these implications of each discipline, and to establish a mutual understanding, this study used an existing 3D pattern design system to demonstrate an example of a 3D block flattening, in practice. It was considered that this would, at least, consist of a foundation for further pattern development.

Another significant contribution of this study was the creation and the digitisation of a real 3D solid garment form which enabled a comparatively identical environment to be constructed between the real and virtual worlds. Therefore, the possible discrepancies of manipulating a garment form in the virtual world were reduced considerably. Because it was in a solid type, the stability of toiling garment patterns was also controlled consistently. Importantly, the pre-creation of this solid 3D garment form in the real world was from informed knowledge of a basic garment form, based upon comparing six cutting experts' basic block construction (see section 2.4.2.2). The created 3D garment form not only simplify the complex human body curvatures, but was close to garment construction in practice. By doing this, the finding of the electronic discrepancy tolerance was more meaningful and related to the need in reality. Only with expert knowledge in garment design and pattern cutting can this kind of approach be realised and a contribution be made for improvements of a future 3D-PDS.

Finally, from the experimental processes and results, analysed by a garment designer and pattern cutter, it was possible to propose some crucial requirements for future progress based upon the existing advantages of the current 3D pattern technology (see sections 6.4.1~5). Having made this major step from the discipline of garment design and pattern cutting, it ought to be the time for modern technology to take another evolutionary step to make a further progression for the garment industry.

6.2 Analysis of Research

Fundamental requirements of cutting mass garments

The study of 2D and 3D manual pattern cutting methods used by the mass clothing industry enabled the identification of four foundations. These were human body, size, block, and fit (see sections 2.2~5). In general, the garment stand is used together with the idealised human body. The selection of both garment stand and body forms is subject to individual niche market demand where body form, posture, shape, and proportion have been considered individually. This showed that it would be more beneficial to provide the availability of form modification according niche market demand rather than to establish an ideal average garment stand (see section 6.4.3). This was lacking in the 2D-PDS, but could be offered in modern 3D digitising technology combined with 3D-PDS.

A size chart with tables of body measurements was found to be one of the key elements which enabled garment patterns to be produced for mass production. This finding questions why it is still not available in current 3D systems (see section 6.4.2). The lack of such crucial information resulted in 'no intelligent link' between 3D digitising and 3D pattern technologies (see sections 4.3~4). In order to use body measurements, this study found that landmarks would be needed from the initial garment design stage to the final patterns produced (see section 2.3.3, p.2-20), but this is still insufficient in the current 3D-PDS (see section 5.6). Clearly, unless the method of body measurements can be validated and unified, the results of any sizing procedure were not valid (see section 2.3.3, p.2-22).

The block construction was divided as: 'structured' and 'non-structured' in this study (see section 2.4.2, p.2-37). This classification allowed this study to focus only one specific sector, i.e. a structured close fitting garment form. Basic techniques for constructing this type of block were identified as: darting, seaming, and easing; the basic procedures were: landmarks; major horizontal and vertical referencing lines; prepared calico; determining suppression and ease required; finally, controlling the possible manual distortion to the minimum. This identification made it possible to create a 3D solid garment form and to control pattern stability in the real world (see sections 4.2~3 and 4.5).

One of the valuable findings was that suppression can also occur at the centre front and back (see section 2.4.2, p.2-46). In mass garment production, 'straight' centre front and back are used more widely than 'curve'. However, it is not necessary for the centre front or back to be straight. This finding identified one of the valuable features to be investigated further from the existing 3D-PDS, and it also addressed the importance of offering both options in 3D-PDS.

One of the other specific findings was that the current CDI-3D could not provide a good quality pattern using a bust dart through the centre of the bust area. However, on an actual garment pattern, a bust dart is often constructed 2 cm away from the bust point, but this kind of construction caused even further distortions (see section 6.4.4). This deficiency needs to be improved in any future apparel 3D-PDS.

The investigation into the functions of 2D blocks made clear that they provided a secure base for a designer to reference when there was any discrepancy caused in the adaptation to a new pattern, but this full advantage has not been recognised and taken up by modern 3D pattern technology, except for Asahi (see section 3.4.2, pp.3-58~63). However, it has to be recognised that blocks from different sources are related to particular size charts and the idealised body form. This was identified when a comparison of 6 basic blocks from different cutting experts was made (see section 2.4.2). The major finding from this comparative study was the common agreement between the experts on the amount of ease required for a close fitting garment. This finding informed the ease distribution in the construction of the solid garment form (see section 4.2).

The clarification of the term fit and the establishment of a fit-coding model (see Figures 2.15-16, pp.2-56~59) reduced disagreements and obtained a satisfactory procedure between the designer and pattern cutter at the earliest stage of the pre-production process (see section 2.4.2, p.2-36). 2D made-to-measure software has attempted to produce a garment pattern to fit an individual body, but this was valid only for a pre-determined garment style. It was seen possible that 3D-PDS could adapt this fit-coding model to address the individual need of a 3D block according to sizing and size charts in conjunction with the body form, posture, shape, and proportion through the creation of

the 3D block form in the virtual world. By doing this, although individual pattern cutters may leave, a fund of pattern knowledge would still remain within a company (see p.3-36). This would be particularly valuable for companies targeting markets.

The major problems of cutting a garment pattern in two dimensions were identified as: the individual method of taking body measurements (see p.2-22) and the use of the term fit (see p.2-56). More significantly, body measurements do not indicate particular body form, posture, and shape. Yet the results of applying contour body measurements to a flat pattern shape were somehow approximate (see Bray, 1994, p.12; Bunka, 1994, p.58) e.g. the measurements front waist length and 'bust to waist'. This *deficiency* value (Poole, 1927, p.313) showed that body measuring and body shaping need to take place in three dimensions (see section 2.2.5, p.2-12).

This means that garment construction in three dimensions is bound to have a better mutual understanding between garment designers and pattern cutters if the discrepancy tolerance of transferring a surface from 3D to 2D could be established. A 3D garment form (block) with specified grain line, structural lines, and suppression distribution (see section 2.4.2.1, p.2-38) is seen as crucial to begin this mutual understanding (see section 6.4.3). Importantly, the shaping of a body or garment form need to take place continuously, instead of an interrupted representation in three dimensions because shaping one area of the body or garment form would affect the shape and balance of the adjacent areas (see section 2.3.3, p.2-22). This consideration justifies why the Asahi-3D system was not selected for this study (see section 3.4.2, p.3-61).

These identifications and clarifications of the foundation elements in the manual garment pattern cutting process made it possible to make an informed investigation of 2D/3D digitising and pattern technologies available for the garment industry.

2D/3D digitising and pattern technologies

The investigation of 2D/3D CAD systems identified the two main strands of CAD: 'concept design' and 'pattern design' systems. This allowed the study to concentrate only on the 2D/3D 'pattern design' sector. The investigation was divided as: 2D/3D data input and pattern design (see sections 3.2 and 3.4). This division allows this study to focus mainly on 3D data input and pattern design. The five methods of 2D pattern data input were identified as: 2D digitising, 2D scanning; CAD drafting, digitiser drafting, and data transfer. This study took advantage of the existing 2D digitiser to input the manually toiled patterns to be stored in the AccuMark 2D-PDS. This enabled the manually flattened patterns to be averaged and modified, so as to establish a *standard* pattern for, later comparisons with electronically flattened patterns.

2D pattern data inputting offers not only human 'intelligence', but also human 'errors'. The profound knowledge of manual pattern cutting expertise is buried in this process where 3D body construction is the key role. This understanding led to further investigation of the 3D data input methods which consist of contact and non-contact digitising techniques. Ten popular non-contact 3D full body digitising systems were evaluated (see section 3.2.3), and it was found that the clothing industry had not taken full advantage of this technology, nor had any of the systems been developed to link directly with a 3D-PDS. This showed an unbalanced supply and demand between the clothing and modern technology industries.

The LASS (see section 3.2.4) was finally selected for the experiments because its data were converted and ready for use in the CDI-3D system. This development made it possible to obtain 3D garment stand or garment form data. Importantly, the digitisation of the created garment form reduced the possible discrepancies of manipulating a virtual 3D 'garment form'. This is the only study which has pointed out and explored this uncertainty between the real and virtual worlds. It was also found that it could still be difficult for garment retailers or manufacturers to use current 3D systems (see section 3.4, p.3-54) because of the lack of a linkage between 3D digitising and pattern technologies. This deficit also makes it difficult for more complex processes to be solved.

Remember that a garment stand's surface is different from a close fitting garment form's (see Figure 3.26, p.3-69), and garment ease is the vital factor to be controlled in this context. Also, the surfaces need to be defined as inner or outer surfaces (see section 3.4.3, p.3-68). Current CDI-3D has not fully addressed this problem. This identification reflects the importance of acknowledging the relationship between the net body form and the block form (see section 2.5.4, p.2-60).

Up to the present, one has to acknowledge that the curvatures of the block form are obviously different from the net body form. As long as non-stretching fabric is used, the block form is inevitably required because of the body movement factor. This study has demonstrated and confirmed that the limitations and potential of modern technology using the first practical example of evaluating the electronically flattened patterns in an apparel environment. This has made a contribution to viable applications for garment use of any future 3D-PDS.

Although 3D-PDS is a developing area, it was found that almost all of the research was focused on simulating 2D patterns *sewn* together as a 3D garment form and/or draping naturally on the digitised garment stand, e.g. Asahi-3D, Stylios et al., Breen et al. (see section 3.5, p.3-72), and Efrat (see p.3-73). This kind of development was seen as insufficient either to address the concerns of the garment fit or to conform to the way in which a garment designer designs a garment in three dimensions (see section 2.7, p.2-71). This finding reinforced the importance of focusing specifically on the '3D to 2D' electronic flattening.

If 2D patterns already existed such as Asahi's system (see section 3.4.2, p.3-61), then, the garment design must have already taken place. Thus, garment design is modified rather than the creation of a new garment style on a garment form. This could separate the garment design and pattern cutting even more than the use of 2D-PDS. It was also seen as unlikely that a scaled image together with the nuance changes of the fabric characteristics on the computer screen could be used as sufficient criteria for the approval of a garment design.

Because 3D-PDS for garments is a complex hybrid area which combines crafts and technologies (see section 3.4, p.3-55), some discrepancy tolerances between manual pattern discrepancy (see section 4.5.4) and electronic pattern distortion (see section 3.4.3, p.3-68) from 3D to 2D need to be established. This would enable an 'accurate pattern' as understood by pattern cutters to be obtained. In turn, it means that it would be more practical and beneficial to identify the acceptable ranges of the pattern discrepancy or distortion between 3D and 2D. The experimental results gained from manually and electronically flattened patterns in this study have achieved this point (see section 4.5.6 and p.6-11). The understanding and identification of this tolerance make it possible to solve some incompatible conditions which exist between the manual and virtual worlds.

Although it is desirable that all the identified lines which are generated on the 3D garment form are retained if they are transferred to a 2D pattern (see section 2.4.3, p.2-54), it makes no sense to keep all pattern edge measurements identical if it is also causing worse distortion in a pattern. This is the key constraint which is bound to exist in mathematical computation, alone (see section 3.4.3, p.3-68). This finding was confirmed by the experiments in experiment 5.4.B which, meanwhile, justified why manual cutting expertise was deemed to be crucial for compensating for this deficiency.

Above all, it was seen that the quality of a garment pattern and the garment fit were the two main elements which could determine the final pattern approval. Technically, this is determined by garment designers and pattern cutters. This means that if pattern cutting expertise participated in the early development stage of 3D software, the diverse knowledge embedded in the manual pattern cutting would be able to judge and justify the electronic pattern distortion in the first place, i.e. after being flattened (see Figure 3.27, p.3-75). Also, it would be able to point out the requirements of garment dart construction and, in many cases, the need for a straight centre front and back. These techniques are basic, but require skill. Only by understanding the problems as perceived by an expert pattern cutter, can these basic requirements be identified.

The devising of a process to assess an electronic pattern

As already stated (see p.6-1), software suppliers showed no evidence of offering an objective method of comparing and analysing electronically flattened patterns in juxtaposition with manually flattened patterns. To make the investigation possible, it was seen as crucial to devise a method by which the electronically flattened patterns could be examined using manually controlled patterns. Importantly, this method needed to provide not only the demonstration of a practical example in the apparel environment, but also the consistency of control for later viable applications. This meant that, in order to obtain a relatively consistent manual pattern, the human error factors and individuality of pattern cutting methods were required to be reduced to a minimum. Having analysed diverse methods of 2D basic block construction (see section 2.4.2.2) and because the research was focused on 3D electronic pattern cutting, a decision was made to use a 3D manual toiling method to create multiple manual patterns.

In order to control consistency in the manual toiling process, a 3D 'solid garment form' (i.e. the *sample garment form*, see Figure 4.1, p.4-4) was created in the real world in which the ease and fit factors, in conjunction with the function of a 3D block were taken into account. The creation of this solid garment form was important because it enabled three conditions to be controlled: first, consistent manual toiling; second, an identical 3D garment form to be digitised using the LASS; finally, an identical 3D garment form surface to be generated in the CDI-3D system. These three conditions were the major contribution which enabled this study to carry out further investigations. Also, this is a hybrid combination which takes into account the mutual requirements in the manual and CAD environments.

It is important to point out that the creation of the sample garment form was from an informed knowledge of a 3D block construction (see p.6-3). This addressed the availability of a 3D block for a future 3D-PDS in the apparel environment where only 16 control measurements could be employed (see section 4.2.3) and whose construction could superimpose a 3D block form onto a net body form (see Figure 3.26, p.3-69). This process provided a viable application for assessing garment fitting conditions.

Manual pattern discrepancy in this process was reduced by means of constructing repeatedly 20 patterns of each of the 4 pattern pieces; after they were averaged and modified further, the final manual patterns could be regarded as relatively *consistent* patterns. This process offered a relative consistency which would be comparatively identical to the one in the virtual world. Only by doing this process, can a manual pattern be produced more objectively, so that later comparison with electronically flattened patterns can make sense.

A linkage between CDI and AccuMark 2D-PDS was also set up, so that the CDI flattened pattern could be plotted as a full size pattern. This provided the feasibility of assessing the 'contact-fit' condition of the electronically flattened patterns directly on the created garment form, so that any discrepancy between the assembled patterns and the solid garment form could be evaluated, in reality.

The devising of a process by which the pattern accuracy and pattern shape stability of the electronically flattened patterns could be examined by controlling the variables of, sizes, measurements and garment fit in manual pattern cutting was fundamental to the function of this research. This process, based upon manual cutting expertise, of investigating electronic patterns does not appear to have been devised in other research studies. This new methodology is a major step forward in the understanding of 3D computer aided design with respect to the clothing industry.

The purpose of providing this process was to create a comparatively identical condition for the real and virtual worlds. One of the important outcomes of this creation showed that manual pattern discrepancy was not the same as the electronic pattern distortion. This was because the grain direction had been pre-set for each identified pattern shape on the created 3D garment form, e.g. straight centre front and back. However, the finite element analysis used in the electronic pattern flattening could produce a 2D pattern with minimum variation. This showed that the manual method could produce good quality pattern shape, but not always consistent, whereas the electronic method produced the opposite results. A future 3D-PDS would need to combine these two features (i.e. quality shape and consistency) for garment pattern use.

The limitations and potentials of the current CDI-3D system

The study of the practical experiments confirmed that the current CDI-3D system could provide a 'reasonable', but not sufficient, electronically flattened 2D pattern for garments. This is because the 'contact-fit' quality of the electronically produced patterns could be determined by the competence of the user, i.e. if the user could recognise the major dual bending areas to cut a pattern, the system could produce a high quality 'contact-fit' pattern (see experiments 5.5.A~B); however, style line determination was restricted by the positions of the cuts through dual bending areas. This is a great restriction to a garment designer or a pattern cutter and contradicts the function of an apparel 3D-PDS which is to develop an idea from a design sketch to final production patterns.

Having devised this process to make some fundamental experiments using the conditions that apply in garment pattern development, it was found that electronic pattern distortion of a garment pattern was irregular and unpredictable using the current 3D-PDS, when is programmed using mathematical computation alone. However, with the knowledge gained from the experiments, it was realised that electronic pattern distortion could be controlled to a minimum if the dual bending curvature was flattened with a minor 'discrepancy tolerance' in both strain and stress (see experiment 5.4.A). This tolerance may be not an exact distortion because 3D garment pattern surface are not a regular geometric form surfaces, e.g. a spherical surface (see experiment 5.2.2.E). However, this study estimated that if the discrepancy tolerance for both strain and stress could be controlled within 2~3 % (see experiment 5.3.2.A), it still could produce an acceptable quality 'contact-fit' pattern for garments. Besides, 2D pattern shape stability could be validated by checking necessary pattern elements (see section 6.3.5).

One has to acknowledge that, in order to make patterns for a close fitting garment, pattern cutters use a dart transferring method to control the whole process from adapting existing 2D blocks to further pattern development. This empirical knowledge has not been realised by the current 3D system (see experiment 5.3.1.A). Although the current CDI-3D system also provided an alternative or a 'Seam' function to control identical pattern edge measurements between 3D and 2D, the evidence (see experiments 5.4.A~B)

showed that controlling the pattern edge measurements alone produced more distortion in the pattern areas. This finding indicates that a range of 'discrepancy tolerance' for electronic pattern distortion between 3D and 2D is needed.

It was also found that there were some potential features which could be used in the garment pattern design process which were available in the current system, but did not seem to be adapted for garment use. For example, in order to impose a vertical line along the created 3D garment form surface, one can construct a line using (x, y, z) co-ordinates, then, using the 'Converter' program to change the constructed line to a 'UV' curve (see experiment 5.5.A, Figure 5.40), so that this 3D straight line could become a 3D curve line and be placed on the garment form surface as it is impossible to draw a 'real world' straight line on a curved surface in 3D. This process is a great help for a garment designer because he/she can actually control how the grain of the 2D fabric would be arranged with reference to the style. This proves that the concept of grain could be provided in the early stage of design development on the garment stand instead of in the later pattern stages.

Other potential developments of using the current system were also identified as, for example, the potential connection to 3D digitising techniques, the linkage with existing apparel 2D-PDS, and the feasibility of making a link to a '2D concept design' program (e.g. 'U4ia') when it is running in the 3D pattern design system.

The clarifications and identifications of manual garment pattern cutting expertise and the 2D/3D modern technologies available for the garment industry made in this study have confirmed that this new approach communicates between both disciplines, i.e. 3D technology and garment pattern expertise. A further development of this bridge would enable both disciplines to learn from each other, so as to make mutual contributions for a better apparel 3D-PDS in future.

By using this kind of experimental process and analysis, the deficiencies and limitations of the current 3D-PDS were identified, and proposals for further improvements can be made in next section.

Proposing crucial improvements

Prior to further discussion, CDI in Grand Rapids (USA) was contacted in order to verify and justify the criticism of the CDI-3D system in the study. Young's statement¹ showed that there have been almost no practitioners in the garment industry from the early days till the present. He also announced that the new version of the 3D software (i.e. Release 6.0) will be launched in Sept.-Oct. 1998, with improvements to the user interface and the flattening work flow. A crucial integration of the current 3D software together with some of Lectra's 2D programs has been ongoing.

However, Shah² confirmed the new release schedule, but pointed that he has not yet received any further indications regarding this integration plan. He also stated that the 3D software program was closed down in 1996 because, at that time, CDI focused mainly on users from the automotive industry. This showed that there was still very little evidence to convince users from the garment industry. He confirmed the criticisms of the 'Keymarks', 'Grain', and garment 'Dart' which this study made in the early section (see pp.5-89), i.e. these functions are available only when a 3D 'Surface' is developed as a 3D 'Region'. Nevertheless, he emphasised that CDI-3D is the most leading system in terms of pattern flattening and draping. But, despite of this, the problem of the electronic pattern distortion and pattern discrepancy still remains.

Finnegan³ affirmed that the SGI workstation did not take advantage of the UNIX memory management features, i.e. the computer would use the sum of the memories if the second loaded file was bigger than the first one. Also, the 3D system tended to affect

¹ Young (senior technical applications specialist) confirmed that, in the early development stage of the CDI-3D software, the major collaborators were from the automotive industry, i.e. Chrysler and Johnson Control, as well as the aerospace industry. The system was developed mainly to produce composites for cars, car seatings, and aircrafts. Its current major industrial collaborators are still from the automotive industry, i.e. Honda and Lear Corporation. There are also users from the shoe industry, but there are still very few users from the garment industry, despite Inpersuit wet suits, Bula hats, and Kimberly Clark diapers suppliers. However, Marks & Spencer did show its interest and investigate the 3D software (private contact, dated 9 Sept. 1998). Academic collaborators from garment discipline are increasing, e.g. Fashion Institute of Technology and Parsons Schools of Design, but this is mainly on the (2D) 'U4ia' system.

² Shah was one of the 3D software programmers who was involved into the early development of current CDI-3D software (private contact, dated 10 Sept. 1998).

³ Finnegan is the CDI-3D system manual writer (private contact, dated 9 Sept. 1998).

the other adjacent pattern edges when constraining one pattern edge. This confirmed the problem of obtaining a straight centre front and centre back (see experiment 5.3.1.A, p.5-40) as electronic flattening is designed to obtain a 2D pattern with a minimum electronic distortion rather than to consider a pattern shape specifically for garments. Because of this, electronic pattern discrepancy is bound to exist even though pattern edge measurements are controlled to be identical between 3D and 2D (see the 'Outcome and analysis' of experiment 5.4.B and section 3.4.2). These correspondents' confirmation and identification of the limitations of the CDI-3D software from CDI reinforced the value of this study.

Having elicited the foundations of cutting patterns and identified the limitations of the modern 3D pattern technology available for garment designers, it was realised that, despite the importance of a mutual communication path between the 3D pattern technology and the garment design and cutting expertise, 3D-PDS was still a long way from achieving the aims expected of it, i.e. to develop an idea from 2D design sketch to final approval patterns. A concept is proposed in the next section that would be logical to develop for an apparel 3D-PDS through specific stages of development.

In order to establish an effective progression, three considerations need to be addressed. They are: first, to classify stages of development and achievement in the cutting of garment patterns; second, to identify the basic requirements for the first stage of 3D-PDS, based on exploring the limitations identified in the previous investigations; finally, to offer a potential system structure for the first stage of developing an apparel 3D-PDS.

6.3 Potential Stages of the Development of 3D-PDS

The initial research into 3D-PDS recognised that the task was so immense that it was seen as necessary to set up stages of development that were proved but were all linked to each other. This also reflects that, in the real world, the tacit knowledge of manual garment pattern cutting expertise is usually obtained from empirical experience. There may be no clear indications to identify different levels of expertise, but it is generally understood that it is considerably time consuming for any practitioner to master these skilful techniques. The underlying problem, which affects designers and pattern cutters at all stages, is the control of the variables. The two major variables are the fabric and the garment form. By controlling these two variables, the investigation into a future apparel 3D-PDS can be classified into four stages described below. This research project covered only the first stage as this was seen as the most fundamental to be proved before other stages could be undertaken. However, potential ways of how the other stages could be developed are also described.

The first stage stabilised both variables. The research argued that when one particular fabric with one particular garment form type are pre-defined, a 3D-PDS ought to be able to produce 2D patterns which can be ready for use in production. It was seen that any of the future apparel 3D-PDS ought to prove this for its potential users. It was believed that if an acceptable garment pattern could not be produced by a 3D-PDS even when applying only one single fabric together with one particular garment form, there would be no point in proceeding any further. This stage clarified a picture about what parameters and processes are undertaken in a 3D-PDS and investigated the basic electronic pattern distortion using only one single fabric and one particular garment form. The outcome of this investigation showed that this stage could be feasible.

A proposed second stage would be that only the fabric variable is stabilised. This means that the electronic pattern distortion in relation to different garment form types would be examined using only one particular fabric. At this stage, attempts could be made to identify certain tolerance ranges for electronic pattern distortion in conjunction with changes of the garment form types. It would be logical to select garment form types first

as 'structured' and then as 'non-structured' types (see section 2.4). This is because close fitting garment types would provide clear evidence when there is an unacceptable level of fit. Stabilising the fabric variable first is because of its many various characteristics, also, current systematic testing methods⁴, despite the many relevant researches that have been undertaken, are still unable to provide enough data for successful computerisation.

The third stage would be that only the variable of the garment form is stabilised but with various fabrics. Because it would be unrealistic to examine millions of fabrics, it would be more sensible, at this stage, to carry out investigations with some specific ranges of fabric samples to evaluate electronic pattern distortion. An investigation could be made into electronic pattern distortion when different types of fabric were used on one particular garment form. If electronic pattern distortion could be established as parameter tables in conjunction with types of fabric, 3D-PDS could then be developed into the final stage.

The final stage of a future apparel 3D-PDS would be that, without the restrictions to the fabric and garment form variables, a designer could develop a garment style directly from a 3D garment form, through final production patterns, to simulations of the final garment draping appearance in accordance with different types of fabric. This would be an ideal 3D-PDS for a garment designer to use.

When this research began, it was found that the most neglected part of 3D-PDS was the first three stages. However, it was recognised that the very first stage was fundamental to all of the others. This could not only offer a radically new approach, but also justifies why this study focused specifically on investigating the first stage development of a future 3D-PDS for the garment industry.

⁴ The two major testing methods were the Kawabata and the FAST testing.

6.4 Basic Requirements for the First Stage of 3D-PDS

6.4.1 2D Design Sketching Function

2D design sketching is very often the earliest stage for a garment designer to capture his/her design which may be just a rough idea or a clear garment style. Current 2D design sketching systems are capable of carrying out this task. CDI has also developed both 2D drawing (i.e. 'U4ia') and 2D sketching (i.e. 'U4ia Sketching') software, but the 2D sketching program has not yet been working interactively with its 3D system. The representation of a realistic garment surface with fabric image realisation would also be needed. Functions which allow a design sketch to be represented with a swatch is required. Realistic fabric image is one of the design inspirations for a designer working on both garment and pattern design and, by doing this, it can predict the effects of how and what proportions of colours or prints would look in that particular garment design.

One has to acknowledge that, in the mass garment industry, 2D design sketch is one of the earliest guides for cutting a garment pattern. What would be helpful for a designer is the feasibility of access to this tool while working with a 3D-PDS. The main purpose for this requirement is because, even if garment design and pattern cutting are integrated in 3D-PDS, 2D sketching is still a tool which can capture an instant idea quicker than 3D garment construction. By providing this tool in a 3D-PDS, a designer could have not only a guide to construct 3D garment style lines, but also a tool to grasp any new born idea when working during the process of developing an attempted garment style.

6.4.2 Size, Measurements, and Fit Specifications

The size, measurements, and fit specifications are lacking in the current CDI-3D system. The major problem which this would cause is that a user cannot have any idea about the digitised garment stand before a 'Surface' is generated and measuring has taken place.

Sizes and measurements need to be available all the time when designing a garment or garment pattern. In general, the measurements for a specific size representing a certain group of people often use 'net' body measurements. On many occasions, only final garment measurements (i.e. specifications) are identified. An effective way of providing the size and measurement information is to illustrate each control measurements using three sketched views (i.e. front, side, and back views).

The fit specifications (as stated in section 2.5) were specified as a net measurement plus individual ease. By doing this, each of the specific fashion fit requirements can be specified clearly. This implies that an individual garment company can establish its own 'standard' garment fit. In reality, this conforms to the practical demand of the garment industry because each individual garment company has its own individual niche market, it is not appropriate for its 'standard' garment fit to be adapted from one to the other. This requirement can be demonstrated using 2-D and 3-D conditions (on/off and swift) in a comprehensive way. Further potential development of linking with 3D digitising technologies is described in the next section.

6.4.3 3D Garment Stand and 3D Garment Prototype

The common method of mass producing garments is that each individual garment supplier technically uses its own size charts and develops its own 2D basic block prototypes in relation to an idealised human body form. When applying this principle to a future 3D-PDS, the provision of the 3D garment stands and their corresponding 3D garment prototypes (i.e. garment form surface) would need to consider the feasibility of a garment stand and a garment prototype whose form, shape, posture, and proportion are adjustable (see section 2.2).

A technique⁵ to interpret the digitised garment stand data into a surfaced 3D garment stand form surface is needed. In the study, 16 fundamental control measurements for an upper bodice were used to realise a garment form in the virtual world that is identical to the one in the real world. If this minimum number is used, the garment form modification or style design can be conducted by designers more easily. This needs to be developed in conjunction with size, measurements, and fit specifications.

A linkage between 3D-PDS and 3D digitising techniques is regarded as a potential application for the future. For this potential development, three possibilities should be considered: first, the possibility of providing a process to reduce 3D digitised data density; second, the possibility of generating key control measurements by extracting directly from the original or reduced 3D digitised data, so that the technique of creating a garment stand can be improved; finally, the possibility of creating a 3D garment prototype directly from an electronic measuring technique which is in development (see section 3.2.2).

It must be realised that, at this early stage of developing 3D-PDS, the design processes are conducted only when there is an existing 3D garment form surface. It is very unlikely to be the same as taking a 2D pattern and attempting to drape it in three dimensions.

⁵ For example, in Chapter Four (see section 4.2), 630 control points finally controlled a solid surface for the digitised sample garment form. This meant that they replaced 14,000 digitised data. Besides, 16 control measurements were used further to control an identical 3D sample garment form (for upper bodice only) in the virtual world.

6.4.4 3D Pattern Design in a Garment Environment

3D-PDS is also used by shoes and car seating suppliers; however, 3D-PDS in a garment environment requires specific features.

An important tool for designing a garment pattern is the landmarks, i.e. anthropometric body points, used to obtain body measurements for sizing bodies in order that different sizes of garment can be produced. However, it must be acknowledged that the use of body landmarks is different from that of the notch marks on a garment pattern. Basic conditions of the use of 'landmarks' in the virtual world are identified as follows.

POINTS

In garment design and pattern cutting processes, three different types of control points need to be available. First, control points which could be used to select the required data points from the digitised garment stand data, so that the measurements between the selected control points could be measured or modified because an individual user may need to modify the digitised garment stand. Second, control points which could be used to indicate or guide garment style lines to be constructed on a 3D garment form surface. Finally, control points which could be used to identify control measurements on a garment stand in relation to a garment prototype. This would provide designers with control points on a minor 'inflated' garment form (see section 4.2.3, p.4-11).

LINES

It must be emphasised that, although garment or pattern designers use lines to construct a garment style design in two dimensions, an alternative way when working in 3D needs to be re-evaluated. The experience gained from the experiments showed that the process of using UV curves to construct a smooth line on a 3D garment form surface was not only time consuming, but also difficult to control the smoothness of the constructing line, unless considerable modifications were made. An essential technique would attempt to generate automatically a garment style line using the basic guidance of the intermediate points to connect two basic points.

FOUNDATION PATTERN

A technique of producing 3D foundation patterns from which basic control points are specified is needed. This is based upon using the pre-defined control measurements which generate the 3D garment prototype to carry out the corresponding patterns. The principle of constructing the foundation pattern type would be the same, but the placement of the control points on the 3D garment prototype surface would be individual.

FLATTENING WITH DART(S) AND/OR SEAM(S)

In the CDI system, two main types of electronic pattern flattening in garment conditions could be specified. These are flattening with cuts and without cuts. The latter one is excluded in this study⁶. Electronic pattern flattening with cuts, in garment conditions, is classified as two main strands: flattening with dart(s) and/or with seam(s). Fundamentally, any of the two adjacent dart legs in a flattened 2D pattern require to be controlled as identical to each other. The two adjacent pattern edges (i.e. a seam) are also required to be consistent to each other, but in some cases, they may be not, e.g. the two patterns may have different grains or fabrics.

FLATTENING IN SPECIFIC CIRCUMSTANCES

Other cases of the inconsistent measurement of two adjacent pattern edges are, for example, the front princess line and the shoulder line where the two pattern edges connected could be different. This is because the discrepancy can be eliminated by 'easing-in', a common cutting method which is used to shape out a form without adding a cut. Another significant example is the top armscye area which connects a bodice pattern and a sleeve. For these specific techniques in garment pattern making, 3D-PDS would require a flattening technique which could allow designers to control particular measurements to produce patterns with minimum distortion. Pattern validation is essential at every stage.

⁶ This study focused only on a particular fabric (calico). It was obvious that flattening without cuts could only be appropriate where stretch fabric was used. Its potential application needed to be investigated.

6.4.5 Pattern Validation and 3D Pattern Alteration

As already stated (see section 2.6.4.4, pp.2-67~68 and section 3.2.2.1, p.3-16), 2D manual pattern is usually finalised by checking patterns in juxtaposition. This process is the preparation for obtaining a valid pattern, in order that, after grading and lay planning, a final production pattern can be proved. For carrying out this process, a 3D-PDS would need a technique to check those defined basic checking elements. In the context of close fitting bodice patterns, the checking elements were identified as:

- 1 pattern edge measurements (and 3D/2D 'discrepancy allowances', see later)
- 2 fit specifications (i.e. net body measurements and eases)
- 3 dart - width, length, angle, and ending point
- 4 matching - adjacent pattern edges (i.e. length and angle), notches, and ease-in
- 5 direction - grain

Prior to validating pattern edge measurements, it is necessary to define the 'discrepancy tolerance', i.e. a tolerance for a pattern edge measurement when the system is flattening a pattern.

Once a 3D pattern is developed and validated, a technique is required which adjusts automatically the 2D pattern when the 3D pattern is modified. The main principle of this requirement is that the validated 2D and 3D patterns have to match within a particular discrepancy tolerance. This function could shorten the cycle of 3D to 2D pattern development. However, the difficulties of providing this valuable function is recognised.

All the requirements stated above (see sections 6.3.1~5) are based upon exploring the limitations of the current CDI-3D system. These were discussed specifically for the first generation of a future 3D-PDS for garment use. A potential system structure is discussed and illustrated in next section.

6.5 A Potential System Structure of an Apparel 3D-PDS

Figure 6.1 demonstrates a potential structure for the first stage of an apparel 3D-PDS linking with an apparel 2D-PDS. However, the function of 'pattern validation' is seen as also possible to take place in the future expansion of the existing 3D-PDS.

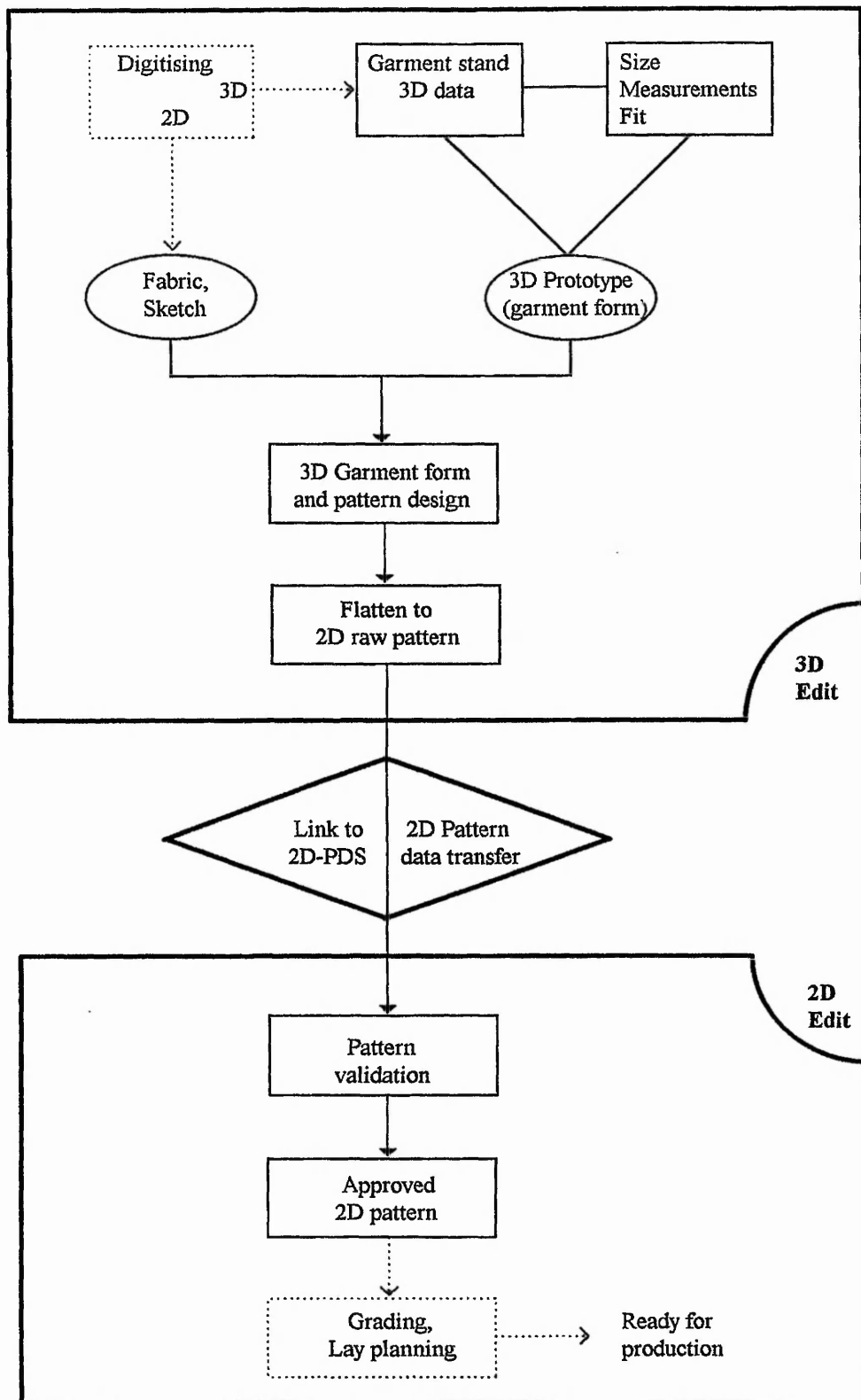
The garment stand 3D data together with the size, measurements, and fit specifications are the two most fundamental elements to be input into the 3D-PDS by the 3D digitising technologies available (see section 6.3.2). A fast prototyping technique to obtain a 3D garment stand and a 3D prototype garment form in accordance with the selected garment stand and the related information (i.e. size, measurements, and fit specifications) is seen as vital for a garment designer to begin his/her design idea. The obtained garment stand and garment prototype would require basic control measurements to be modified; these measurements are used to generate an effective form surface (see section 6.3.3).

Together with the 2D scanned⁷ fabric image and 2D design sketch (see section 6.3.1), the designer could then determine a specific fitting type of garment form to develop a new garment style. The 3D pattern needs to be able to be modified directly on the garment form. Basic requirements for designing 3D garments and patterns were discussed in section 6.3.4. When being flattened to 2D raw pattern, the 'discrepancy tolerance' factor (i.e. the minimum electronic pattern distortion between 3D and 2D patterns, see section 6.3.5) needs to be verified.

Thus, the 2D raw pattern data could be transferred to a linked 2D-PDS. By doing this, further verification of the 2D raw pattern could be made by means of checking the five elements stated in section 6.3.5 (i.e. the pattern edge measurements, fit specifications, dart, matching, and direction). Once the discrepancy of the pattern edge measurement is caused, the pattern should be able to be modified directly on the 3D pattern. The corresponding pattern changes would also need to be verified. By repeatedly verifying these basic checking elements, a final approved 2D pattern could be obtained.

⁷ Alternatively, it could be a fabric design drawing image transferred from another concept design system.

Figure 6.1 A potential system structure of an apparel 3D-PDS



Note: '2D/3D digitising' was discussed in Chapter 3; 'Grading/Lay planning' was excluded from this study.

7 CONCLUSION

7.1 Summary

This research has contributed a crucial step for progression to be made in a future 3D-PDS. It has provided a process by which, for the very first time, electronically flattened patterns could be investigated in practice in the real world. In particular, the results of this investigation process demonstrated that the success of a 3D-PDS for garment use needs to be proved by its real users, i.e. designers and pattern cutters. This has been lacking in current modern technology development and related academic research. Importantly, the lack of a mutual communication between the garment and modern technology industries was solved by analysing the basic appreciation of modern technology in juxtaposition with fundamental requirements of manual pattern cutting expertise. The accomplishment of this major step provides opportunities for further developments and improvements of a future 3D-PDS for the garment industry.

This study started, in the beginning, from an investigation of the possibility of establishing a communicating path between garment designers and pattern cutters. Later, it was found that the current 3D-PDS, which integrated garment design and pattern cutting electronic techniques, might be capable of carrying out this function. At that time, 3D systems available showed many visual effects, for example, garment draping, rotating, and 3D images of the garment appearance (see section 3.4.2). However, its potential and practical limitations for use in the garment industry have not been made clear to garment designers or pattern cutters. The researcher, as a garment designer who usually constructs patterns in three dimensions (i.e. modelling on a garment stand), decided to examine this technology.

The hypothesis stated (see section 1.2, p.1-2) that, 'if all variables are controlled in a comparatively consistent condition (between the real and virtual worlds), 3D

electronically flattened patterns ought to show an equivalent quality fit in the pattern edge measurements and shapes when compared with manually toiled patterns'. This was seen as a necessary intermediate phase prior to obtaining consistent patterns in a future garment 3D-PDS.

Having offered this hypothesis, it was then necessary to create a process through which it was possible to conduct experiments both in the real and virtual worlds. The creation of this investigation process was based upon the expert knowledge gained from previous studies of manual pattern cutting and the 3D/2D CAD systems available for garment use.

From the experiments included in Chapter Five, particularly in experiment 5.4 (p.5-65), it was found that, even though all the relevant variables were controlled to be comparatively identical between the real and virtual worlds, electronically flattened patterns did not provide the same quality of contact-fit as manually toiled patterns. The limitations could take place where darts or seams were not constructed in the precise dual bending areas with 2 cuts perpendicular to each other, as well as where pattern validity and the size and measurements regarding the input garment stand data were not available in the program.

However, with its potential viability of integrating garment design and pattern cutting, further applications could take place if the identified limitations (see section 5.6) could be explored. This study has provided evidence to clarify the electronic pattern distortions and deficiencies. Potential improvements for developing a future 3D-PDS for the garment industry have also been identified (see section 6.4) to comply with the specific use in a garment environment.

The three aims of this study (stated in section 1.2, in Chapter One) were: to investigate the garment CAD software available and its viability from a garment designer's and pattern cutter's perspective in order to share knowledge to establish its potential application in some areas of practice; from this specific perspective, to provide evidence for the viability of the garment pattern shapes when electronically flattened and to make an analysis in a way that would make sense to garment designers and pattern cutters. Specification of the deficiencies, limitations, and potential of the current 3D-PDS could

then be addressed fully for use in an apparel environment; and finally, using this approach to propose further improvements for a future 3D-PDS to meet the demands of garment design and pattern cutting.

Based upon a garment designer's and pattern cutter's viewpoint, this study has clarified the comparative foundations for electronic garment pattern cutting, and has investigated and compared electronically flattened patterns both in the real and virtual worlds. A classification of the stages of development for future apparel 3D-PDS has also been identified. Because this is a designer's approach to examine the current 3D technologies, it enabled the researcher to devise a process by which the experiments and the comparison to the electronically flattened patterns could be demonstrated and illustrated in a way which a beginner, particularly a garment designer or a pattern cutter, would also be able to learn the basic knowledge from the available 3D-PDS.

The current 3D-PDS is still based upon flattening a 'contact-fit' pattern, i.e. skin-off. However, 3D manual pattern making is often individual and questioned because it includes garment ease which could make pattern distortion unclear. This was seen as 'non contact-fit' pattern making and was often more subjective. Consequently, it could be argued that this subjective solution could be used to verify the electronic pattern distortion. To solve this argument, the way of manual pattern making had to be modified as the same to the 'non contact-fit' pattern making method in order that a comparative environment could be established identically for the real and virtual worlds. This modification could reduce the subjective factor to a minimum, and could obtain more effective pattern comparisons because the manual foundation pattern was controlled relatively consistently.

By devising this process, the insight of manual garment pattern cutting was demonstrated and illustrated in juxtaposition with current 3D technologies. Particularly, the creation of a solid 3D garment form surface reduced the inconsistent use of the term garment fit to a minimum. This process enabled a foundation pattern to be obtained in the best consistent manual condition. The consistent foundation pattern stability in the real world was the most crucial criterion which enabled this study to further investigate electronic patterns.

was deemed that the insight of controlling the consistent foundation pattern in the real world could assist to obtain a satisfactory pattern in the virtual world. Importantly, it provides a concept that electronic pattern flattening needs to demonstrate this important element, i.e. garment ease, which is fundamental for garment pattern design in the real world.

It was noticed that, in the real world, when a 2D pattern is approved and modifications made by seaming or darting, the pattern areas and pattern edge measurements remain stable. This has not yet been achieved in the current 3D pattern flattening process. This is because each electronic pattern was flattened as an individual piece. It was seen as rarely possible to obtain two electronically flattened patterns with an identical distortion. Because this limitation was embedded in current 3D-PDS, manual cutting expertise was imposed to rectify the distortion to a minimum, so that an acceptable 2D garment pattern could be obtained and ready for use in later production stages.

It was also realised that if a designer is creating a close fitting garment form in the real world, the designer has tools with which to create the shape and which give the designer freedom to design. The tools are seaming, darting, and easing. The only tool the system provides to flatten a pattern sufficiently but specifically is seaming (i.e. cutting). Despite this, 'grain' is the key criterion to examine pattern stability, but the grain is treated as a pattern feature rather than an important guide to verify the pattern shape stability (see Chapter Five).

The 3D software programmer has to recognise the feasibility of design and pattern cutting in the real world of a garment environment. This study found that one of the most crucial elements to control the manual pattern stability was based mainly on achieving consistent grain direction between the formed 3D pattern and the flattened 2D pattern. The processes and experimental results of this study provided a useful base where, later in Chapter Six, the fundamental requirements for improving a future 3D-PDS could be investigated in relation to the deficiency of current 3D-PDS.

From the experience gained through the experimental results, it was found that it was possible to obtain a reasonably close fitting pattern shape, but it was not sufficient and

could only be obtained under restricted conditions. Garment designers have to accept that electronic techniques came from different disciplines, and different skills would need to be learned, e.g. stress and strain analysis. An understanding of the significant dual bending areas of the garment form surface becomes an important guide for a designer to obtain better quality contact-fit patterns. However, it is certain that garment designers will only use the new technology when the system can provide equality of pattern with a minimum restriction in the design process.

Finally, it was acknowledged that the feasibility of thinking and visualising a design idea in three dimensions combined with consistent communication skills is an important quality for designers to carry out their creations.

This study took the stance that the strength of potential modern technologies should be to realise the above statement to the benefit of the garment industry. The research itself is not going to solve the whole problem of current 3D CAD technologies, but it is a good start in providing a clear picture to revolutionise the modern technologies available, by demanding the quality and specifications which the garment industry requires.

7.2 Prospective

Having realised how long it takes to obtain final approval for a selected garment design by major garment retailers and garment manufacturer (see section 2.6), 3D-PDS is seen as an effective communicating and competitive tool for the future garment industry to shorten this cycle, i.e. from an idea to a final garment approval. Many researches have been undertaken in this field; however, practical evidence to show its feasibility is scarce. Particularly, the most fundamental part, i.e. 3D to 2D pattern flattening, has not yet been demonstrated by current 3D systems available.

Despite the establishment of a mutual understanding of 3D modern technologies and garment pattern cutting expertise, together with a proposal for a potential system structure for a future apparel 3D-PDS (see section 6.4; Figure 6.6), this study has classified, in the context of close fitting garments, the four stages of development for a future apparel 3D-PDS (see section 6.2) and has confirmed the importance of the first stage of development. Further stages of development are also seen as a prospective task.

Other potential research areas generated by this study can be seen as important to investigate further. First, this study focused only on women's upper bodice garments of a close fitting type, the process which was devised in this study could be applied to investigate other kinds of garments, e.g. lower bodice garments (such as skirts and pants), sleeves, and men's garments.

Second, another potential development for 3D-PDS is the connection with existing 3D digitising technology. This could provide a consistent method of acquiring body measurements. By doing this, it would expand the use of the made-to-measure software. As stated in section 3.3.2, the Telmat body measuring system attempted to connect with the Gerber made-to-measure system; however, as the acquisition of body measurements between both systems have not been made to conform to each other, the processed patterns were not validated for use at that time. Other apparel research groups or companies, such as Clemson Apparel Research and Clarity Fit Technologies have also been working on this type of development.

Third, when the first stage of a future apparel 3D-PDS could be proved, '3D grading' would be seen as a valuable progression in the mass garment industry. Once the control points for a 3D garment prototype could be developed, together with the size, measurements, and fit specifications, garment grading would no longer be to grade the 2D pattern shapes, but to shape the 3D garment forms in relation to the idealised body form types. This would provide an opportunity for making mass produced garments in a more effective way.

Fourth, garment design is a two-way approach, i.e. '3D to 2D' pattern flattening and '2D to 3D' pattern wrapping. This study only investigated '3D to 2D' pattern flattening, whereas most other researches have been involved with '2D to 3D' pattern draping. However, it is also seen as important if it could be possible to devise a process to examine this '2D to 3D' pattern draping.

Finally, the best features of a pattern design system are not only about how many functions it has, but about how efficient and practical are functions which the system provides for its users. The basic requirements for the first stage of an apparel 3D-PDS have been specified in the study; however, the best use of the 3D CAD tools is seen as an important area to be evaluated further. For example, some functions which are seldom used and occupy the computer memories may be better removed.

It is understood profoundly that the real potential future for an apparel 3D-PDS is that it needs to be developed by a research team which should include garment designers and pattern cutters, as well as 3D software programmers. The major contribution of this study is not about the investigation itself, but about future development based upon this investigation. Clearly, without a mutual understanding, 3D-PDS may represent a risk rather than a benefit for the mass garment industry.

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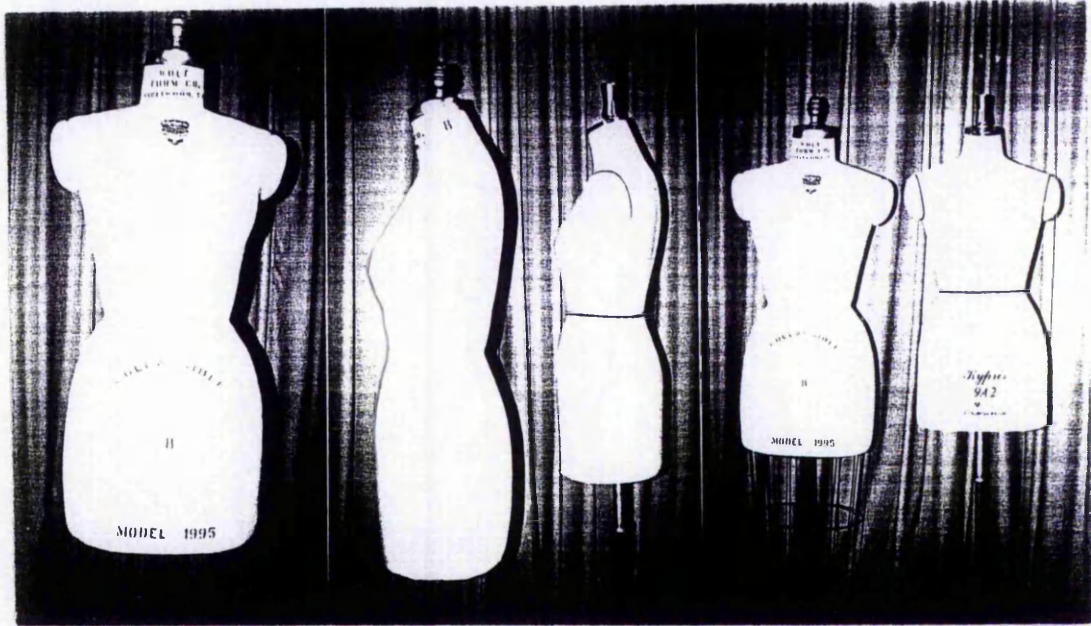
Appendix 1 An interview with cutting practitioners regarding the criteria for selecting a toile fabric for making a skin-tight block on the garment stand

	Calico Light A2085	Calico Light Medium	Calico Heavy	Calico Scoured AJ404	Natural Scoured Cotton	Scollata Cotton	Plain Cotton	Reasons
Aldrich				X				Because it has been scoured (i.e. it has been washed and finished), it helps the shape. Also, because it is medium weight.
Goulding				X				The performance of the fabric in relation to the finished garment, i.e. weight, drape and shear.
Brown							X	Because it has been bleached & dyed, the fabric will not shrink or grow after ironing.
Bushby					X			It is firm enough to shape it, and soft enough to shrink and shape.
Byrne				X	X			It is soft and subtle, and can be moulded onto the garment stand. For this particular use, the calico has to possess more malleable characteristics.
Danjoux		X						It is a good structure to achieve the shape. Also, it is tight weave, it will not stretch too much when modelling.
Keen		X			X			Considering the stiffness and softness for the type of garment.
Pinches			X					The natural scoured cotton is chosen for long term use, and the medium calico is chosen for this experiment.
Stafford					X			Because of its stability and reliable weight. It requires stability but it is not too heavy. It feels soft and flexible, also the weave is not too open.

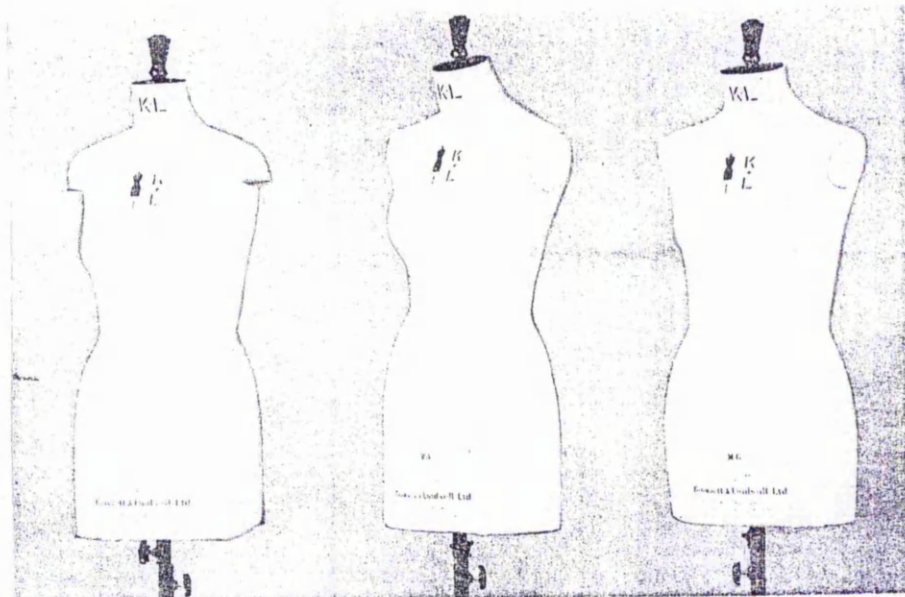
Note: The three most popular selections were experimented with. The medium calico was found to be the most appropriate for this project because of its stable construction.

Appendix 2

A selection of stands, demonstrating the range of stands available to the clothing industry in the UK

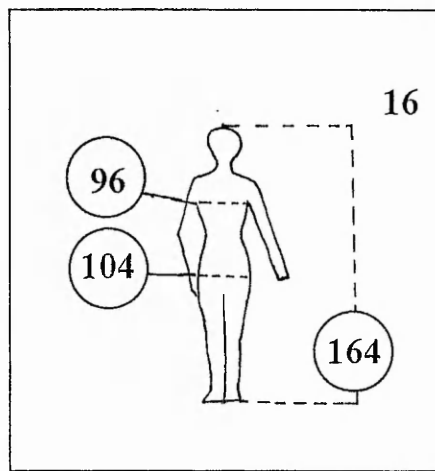
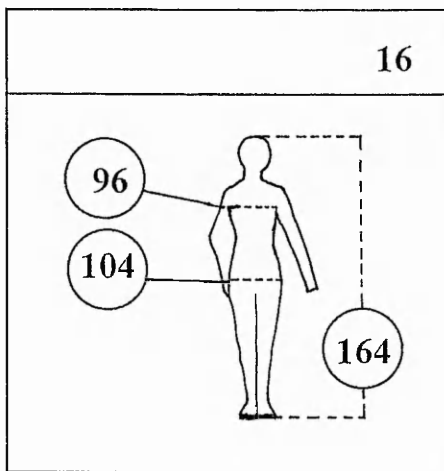


These garment stands were produced in USA and Japan (courtesy of MerryMax bridal corporation, based in Taiwan, direct contact, dated Jan. 1997).



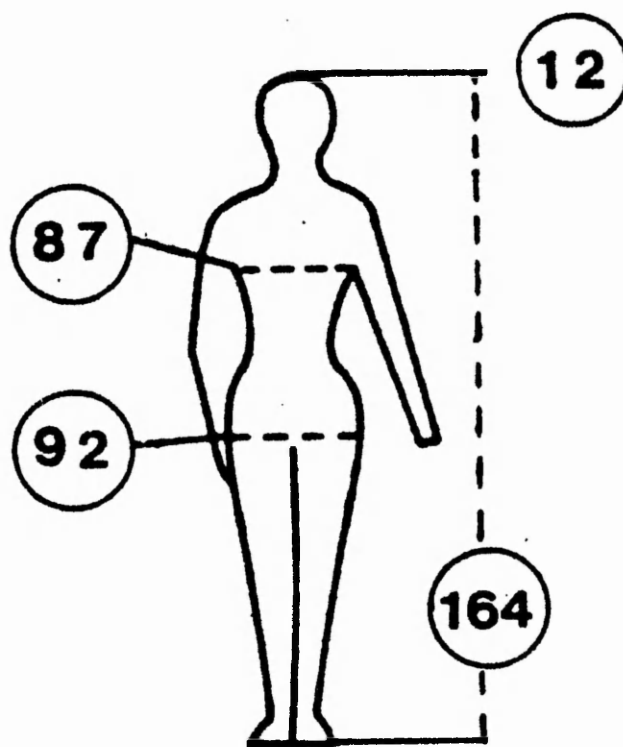
These garment stands were featured in the brochure which was provided by 'Kennett & Lindsell Ltd', based in the UK (1996).

Size codes	Body measurements			
	Hips		Bust	
	from	to	from	to
	cm	cm	cm	cm
8	83	87	78	82
10	87	91	82	86
12	91	95	86	90
14	95	99	90	94
16	100	104	95	99
18	105	109	100	104
20	110	114	105	109
22	115	119	110	114
24	120	124	115	119
26	125	129	120	124
28	130	134	125	129
30	135	139	130	134
32	140	144	135	139



Examples of inclusion of size code number into label

These figures were featured in 'BSI 3666: 1982 Coding System'.



A pictogrammatic illustration showing the control measurements for size 12.

This picture was featured in 'Modern Sizing and Pattern Making for Women's and Children's Garments' (Kunick, 1984).

(1) In 1963 (BS 3666: 1963)

A comprehensive size coding scheme for women's outerwear was initially published in inches. It is worth noting first, that *no definite values* were provided and the variation was ranged for a 2-inch allowance; and second that the *size intervals* varied, for example, from 1-1 1/2 inch steps in smaller sizes to 2 inch steps in the larger sizes (Kunick, 1984, pp. 13-14).

(2) In 1974 (BS 3666: 1974)

The system was revised in metric form. The size intervals then varied from between 4 and 5 cm. The difference of the two coding schemes between 1963 and 1974 was that the horizontal limitations for each size were indicated for the two purposes: first was to provide for accommodating the different practices of the 'light and heavy' sections of the clothing industry; second was to provide for the *disproportionate figures*. However, the main body measurements were still given *no definite values* (see Appendix 2.3) within this coding scheme (Kunick, 1984, p.13).

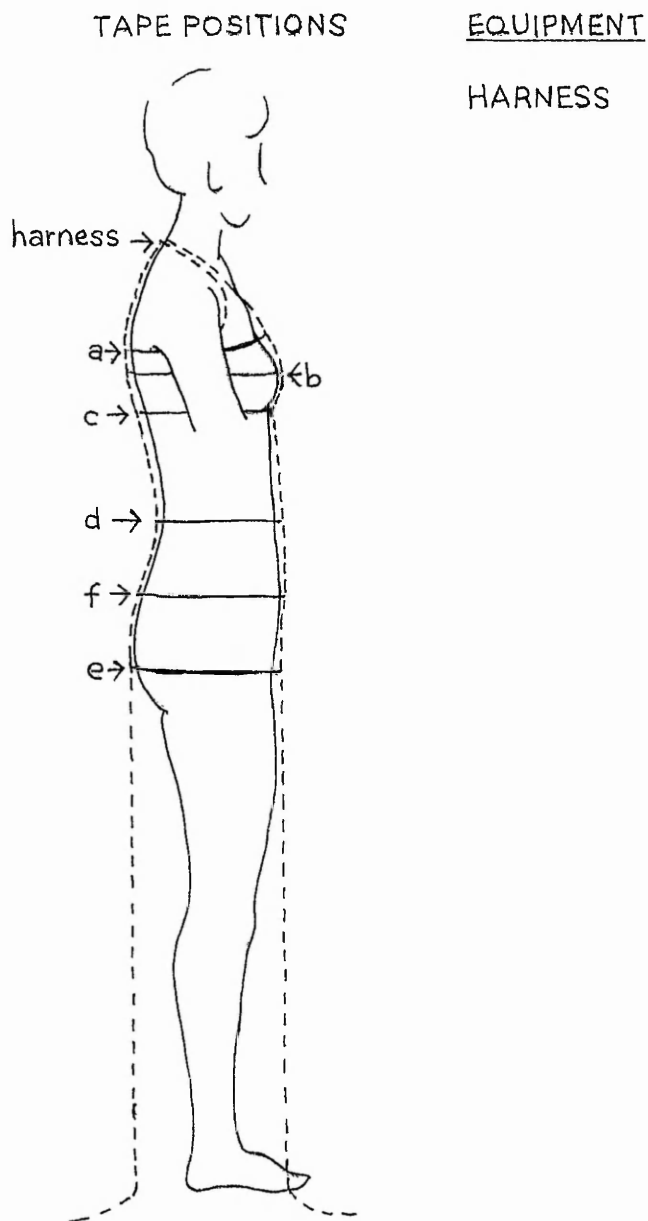
(3) In 1982 (BS 3666: 1982)

The size coding system had its second revision. The development of women's sizing in the UK is generally recognised as having been established from this period. Later on, it evolved with explanatory labels to cover the two separate areas of women's wear, namely: Women's Outerwear which consists of five garment categories 'jacket, coat or dress, slacks, cardigan and skirt' and Women's Underwear which in turn consists of four garment categories 'brassiere, pyjamas, girdle and sports shirt'. (Kunick, 1984, p.14)

Landmark (control point)	A mark placed on the body specifically for identifying the anthropometric points (these refer to medical anthropometry) or control points (these refer to garment technology) to obtain the body measurement.
Control measurement	The body control measurement that is chosen to divide the survey subjects into groups for later size coding.
Sizing	The action which classifies the various body figures with reference to anthropometric measuring data.
Size interval	The basic difference between one size and the next size.
Size code	A reference which is specifically used to indicate body figures in a group, either by numerical or alphabetical system.
Size chart (size table)	The results obtained from a sizing survey which are established into a statistic relationship generally within a size coding system.
Standard sizing	An average size which consists of a set size code consisting of generally agreed and defined values of the body measurements.
Sample size	A foundation size which is generally used to make-up and test the sample garment, and then used to grade up or down from an approved garment sample.

It is not generally agreed which net body measurements should be used for the sample size because it appears that there is not a standard average body figure which covers the majority of the population.

The sample size usually relates to the size range in which it is set, for example, a size 12 is appropriate in a size range 8-16. However, criticism has been made of the use of a size 12 sample in a range 10-20. The size 12 is often retained because the garment is usually more flattering on the size 12 figure, and is therefore more appealing to buyers.



This harness consists of two tape measures fastened at right angles at the zero measurement. They are attached to an adjustable elastic which is positioned from the nape of the wearer, over each shoulder, around the forearms, under the arms and fastened across the back at armhole level. These harness tapes are held close to the body by the elastic tapes.

Note: This figure was provided by Beazley at the measuring training course for the 'GUS' survey in May 1996 (The company GUS, based in Manchester, was one of the biggest mail order companies in the UK. Their products ranged from garment to the related accessories).

Appendix 8 Kunick's method of sizing bodies

The diagram which is quoted from Kunick (1984, p.20) shows the distribution of bust sizes from the majority of the female population in the UK in 50's. It is grouped by Kunick as 'inner box' and 'outer box' to indicate the female body figures regarding the relationship between hip and bust girths. The 'inner box' covers 72.9% of the population, whereas the 'outer box' covers 96.9% of the population. However, it is argued that the 'outer box' can be more effective and cover the majority of the population if the hip sizes are ranged between 32 and 50 inches. By doing this, it covers 97.8% of the population, whereas the original 'outer box' covers 96.9% of the population.

Moreover, the extension of the range vertically to the outer box does not imply the need for extra size charts, but is an extension of the sizes created for the inner box.....
 Although the numbers above the inner box are fewer, they are important because they represent the market of the outsize specialists. Kunick (1984, p20)

Distribution of Bust Sizes (inches)

Hip Girth	Bust Girth Larger		Bust Hips Equal	Bust Girth Smaller				Totals
	+4"	+2"		-2"	-4"	-6"	-8"	
Inches	%	%	%	%	%	%	%	%
52			-1	-1				.2
50		.1	-1	-2	-1			.5
48		.1	.3	.4	.3	.2		1.3
46	.1	.3	.6	.9	.3	.3	.1	3.0
44	.1	.5	1.3	1.9	1.5	.6	.1	6.0
42	.2	.8	2.5	4.0	3.2	3.11	.1	11.9
40	.2	1.3	4.4	7.2	5.4	1.5	.2	20.2
38	.2	1.8	6.3	10.0	6.4	1.3	.1	26.1
36	.2	1.7	6.2	8.6	4.0	.5		21.2
34	.1	1.0	3.0	3.1	.9	.1		8.2
32	.1	.3	.5	.3				1.2
Inner box			20.7	31.7	20.5			72.9
Outer box		7.6	24.8	36.4	22.5	5.6		96.9
All sizes	1.2	7.9	25.3	36.7	22.5	5.6	.6	99.8

Appendix 9 **'Block, Pattern' and relevant terms used by the other garment cutting experts**

- Block** Aldrich (1994, p.17): The blocks include the basic amount of ease required for the function of the block.
- Block pattern** Aldrich (1994, p.17): A block pattern is a foundation pattern constructed to fit an average figure.
Bray (1994, p.9): The function of a Block or Foundation pattern is to provide a simple outline of bodice, skirt or sleeve, from which every kind of style pattern can be developed. It must also serve as a map or chart for recording useful information about the proportions, shape and even posture of a figure, average or individual.
Shoben (1980, p.38): Block patterns are used in industry to provide the pattern cutter with a basic shape from which are developed many different garment designs.
- Standard block** Bray (1994, p.10): 'the basic foundation' which follows the natural lines of the /Basic Foundation figure and is little influenced by other considerations'.
A Standard block may be neutral, i.e. it need not emphasise fashion exaggerations, but it must never be 'old-fashioned' in line and fit'.
- Primary blocks** Bray (1994, p.12): The three Primary blocks are the Bodice, the Straight Sleeve and the Standard Skirt'.
- Intermediate blocks** Aldrich (1994, p.17): are basic shapes that are in use continually, for example the kimono block, the 'A' line skirt block or a particular shape on which a range of designs has been based.
- Secondary blocks** Bray (1994, pp. 9-12): as the Shaped and the Tight sleeves, the Fully Shaped or the Straight skirt, various collars, the Raglan, the Kimono block and others.'
- First pattern** Shoben (1980, p. 8): The original pattern, cut from the working sketch, is called the *first pattern*. This is used to cut out a 'toile' or calico.
- Trade block** Bray (1994, p.11): The Trade Block is an adaptation of the Standard block made to suit various requirements of the wholesale manufacturing trade'.
- Tailoring block** Bray (1994, p.11): is yet another adaptation of the Standard block which introduces a few special figures and proportions characteristic of most jacket patterns drafted by tailors.

Close-fitting - block (sloper)	Refers to a garment prototype with constructive lines which are 'unwrapped' from the ' <i>primary garment</i> ' (note 1) form for a ' <i>live</i> ' (note 2) body. The 'fit' divides this base block into more different characteristics of block construction (stating in 3.5 'The use of the term 'fit' in the garment industry'). 'Sloper' is an American term for a block.
Basic block	It is a base block from where another garment construction can be accordingly developed within 2D modification. The fashion factors, such as style lines or components are not considered for this block.
Fashion block (Seasonal block)	Whilst based on the basic block, it has been slightly modified according to fashion factors, such as the degree of fit in accordance with the concurrent season.
Pattern	Refers to a garment prototype with construction lines which has been generally derived from a basic or seasonal block. It has been modified according to the new garment style required. This prototype will consist of style and fashion components.
Foundation (Block) pattern	Refers to a paper prototype between a block and pattern. This prototype has been modified to a specific garment appearance, e.g. Kimono sleeve or leggings.

Note 1: This means a garment which is 'wrapping' a body as close as possible within an acceptable and satisfactory garment appearance. This also considers the required ease for the body comfort and movement. The fashion factor is not considered within this block construction

Note 2: This means with certain ease for body comfort and movement.

The Nature of MEI

Martin International is a public limited company, Martin Emprex International and Martin's are all under its name. Martin's is dealing mostly with Marks & Spencer, whereas Martin Emprex is more linked with Mothercare, Debenhams, Dunnes Stores.

MEI is concentrating on a middle market with a traditional but new conceptual sense. Its particular market is lightwear (e.g. nightwear, lingerie, blouse) and children's wear. In departmental structure, it includes design (& cut), fabric, costing, grading, merchandising in one floor. Sample machining and warehouse are separately located surroundings. It actually contracts its manufacturing to overseas factories, such as Sri Lanka, Mainland China, Pakistan...etc.

Future plan in MEI

Martin Emprex International was reconstructing the departmental allocation. Initially, design and sample machining departments were located nearby, however, in order to receive quicker and more efficient information from the state-of-art market, MEI recently organised design and merchandising departments.

Meanwhile, MEI is going to replace the old CAD system ('Cybrid' Layplan System and Pattern Grading System). It is expected that it will be replaced by the 'Investronica' System by Christmas 1995. This is because the other relevant enterprise have all installed Investronica, and it will link work more efficiently by using the same system language.

Although material costs are getting higher and higher, the raised prices can't be transferred directly to the customer. Alternatively, MEI is expecting to reduce the labour costs and to work more effectively after a new CAD system is installed.

History of Meritina

Meritina is the former Nottingham Manufacturing Company Ltd., which had a long history in the clothing industry. It produced mainly knitwear, outerwear and hosiery and also had a carpet-making subsidiary.

Meritina became a part of the present Coats group when a series of mergers were carried out in 1980's. There are four companies which make up the Coats group, they were set up during 1960's and 1970's¹.

(1) Vantona

deal mainly with household textiles, table linens and uniforms.

(2) Carrington Viyella

was formed in 1969, and produced mainly staple and filament fabrics, shirts, as well as home furnishings

(3) Nottingham Manufacturing Company Ltd

(4) Coats Patons

had its origins in the thread business of J&P Coats, when it took the initiative in producing cotton sewing thread in the 18th century.

The other business it owned were Patons & Baldwins hand-knitting yarns, West Riding yarn, and Dynacast precision engineering.

¹ Note: Resourced from 'Coats Viyella plc. and Tootal Group plc' - A Report on the Merger Situation. Performed by the Department of Trade and Industry, and published by Her Majesty's Stationery Office, 1989)

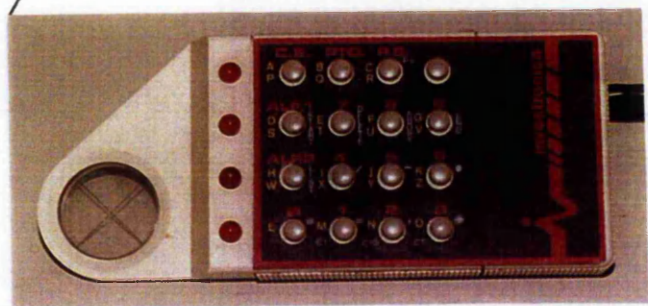
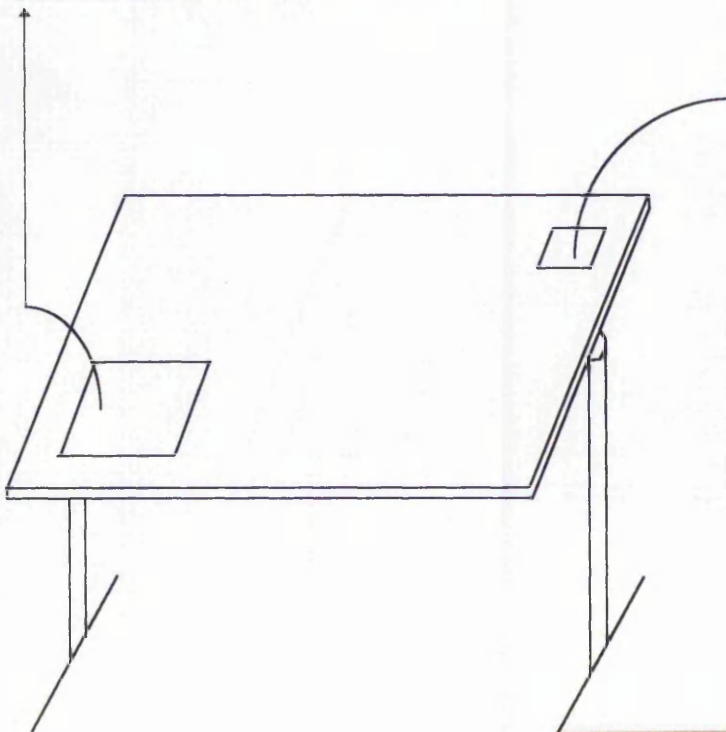
Coats, a leading international textile & clothing group, has production ranges for yarn, sewing thread, fabric, garments, household textiles, carpets, knitwear, garment trimming, as well as precision engineering products.

Nature of Meritina

Although Meritina is known as a part of the Coats group, in fact, there is no direct working relationship between them. It produces garments mainly for Marks & Spencer in Men's wear (suits, jackets), women's wear (lingerie, nightwear, blouses, dresses) and children's wear.

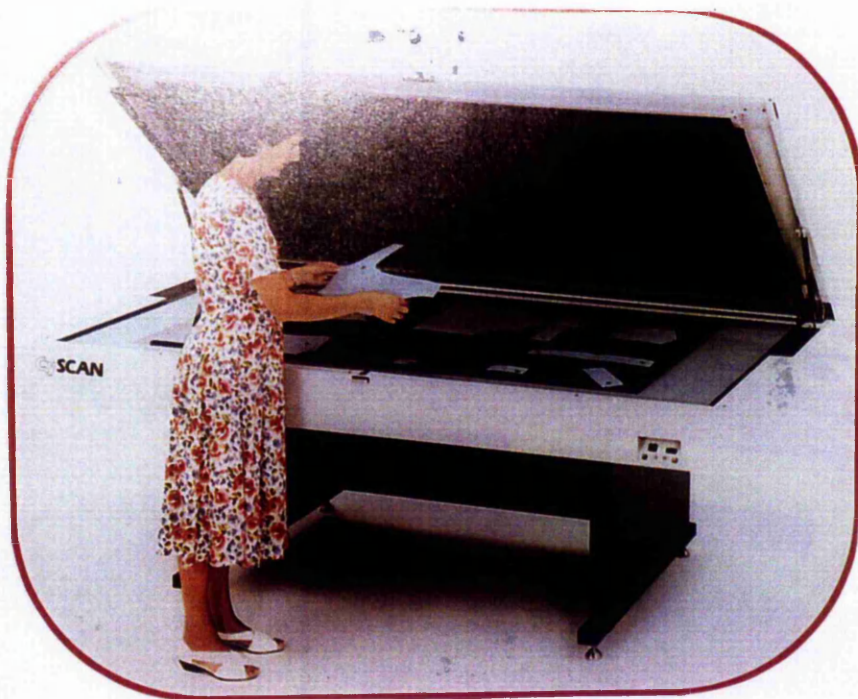
Meritina is an organised clothing manufacturer. It produces the garment from the original design concept through to the process of engineered till bulk cutting, and then sends the goods to factories in the UK or abroad for manufacture. There are two contract overseas factories, one is in Macao, the other is in Portugal. Also, it has a huge warehouse for finished garment from the UK or overseas factories.

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Note: This digitising menu and the alpha/numeric puck are featured from the NUMONIC, A 100S. A model which is configured with GGT AccuMark system. Other types of pucks such as, Lectra's (right middle), and Investronica's (right bottom) are also referenced.

Appendix 14 The '2D scanner' for inputting garment blocks or patterns



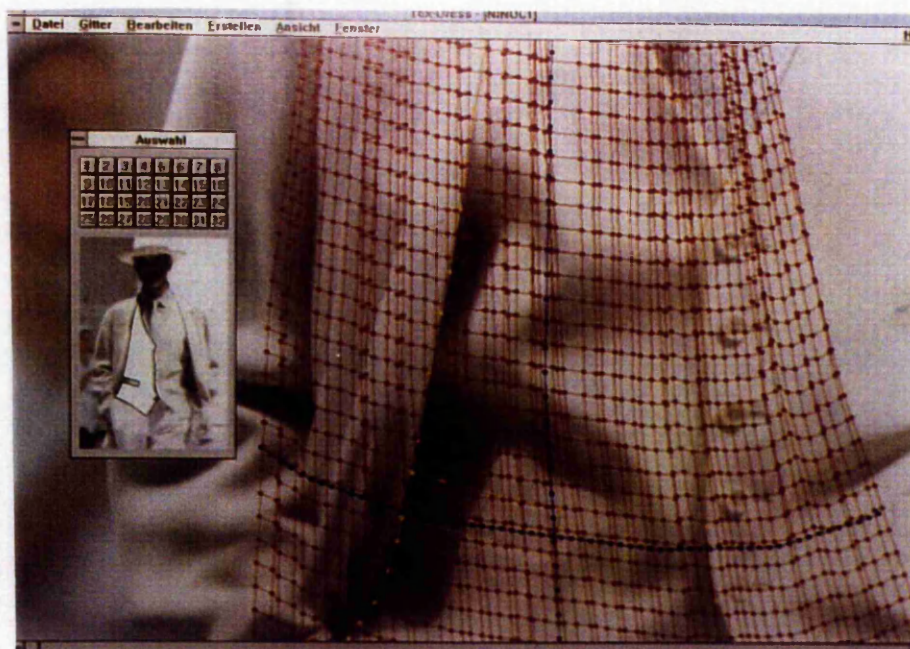
Note: This picture was featured in the Cybrid International CAD systems' brochure which was provided in the '1994 CloTech' exhibition in the Harrogate International Centre, Manchester, UK.

Appendix 15

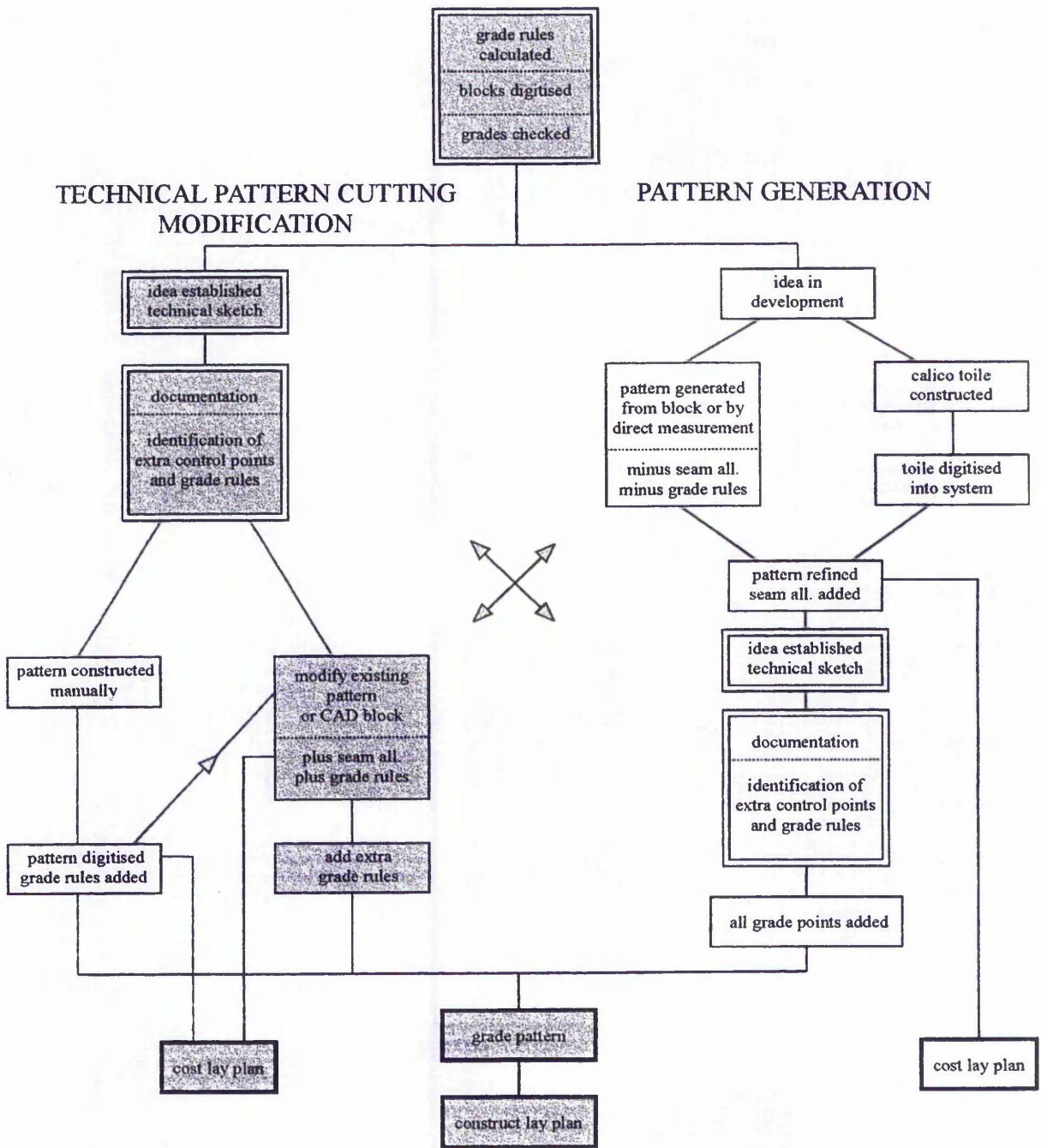
The comparison between the Symcad and manual measurements

1 Tour de cuisse droit / R. thigh girth 63.1 62	13 Longueur entrejambe Homme / Crotch height 66.9 69 : 67
2 Longueur manche / Sleeve length 50.1 54	14 Tour de ceinture / Mid-hip girth 81.7 92 : 93
3 Tour de cuisse gauche / L. thigh girth 62.7 62	15 Tour de jarret droit / R. heel girth 36.4 29
4 Tour de jarret gauche / L. calf girth 35.9 36	16 Tour de mollet droit / R. calf girth 37.2 36.5
5 Tour de mollet / L. heel girth 36.3 36	17 Tour de cheville droit / R. ankle girth 31.8 23.5
6 Tour de cheville gauche / L. ankle girth 32.3 23.5	18 Hauteur de corps / Bodice height 135.7 136 : 134
7 Hauteur de seins / Bust height 0.0	19 Stature / Stature 160.2 158 : 156.5 (Re-do)
8 Tour de poitrine / Bust girth 92.4 92.4	20 Tour de taille / Waist girth 72.0 (3D) 72
9 Tour de bassin / Hip girth 100.1 95 : 97.5	21 Longueur d'entrejambe / Inside leg 69.4 68
10 Encolure / Neck (circumference) 33.7 32 : 35.5	22 Carrure dos / B. shoulder width 32.8 34.3 : 36.9
11 Carrure devant / F. shoulder width 34.6 (3D) 33.6 : 34.5	23 Longueur d'épaule / Shoulder length 12.0 12.3 :
12 Longueur de bras droit / R. arm length 50.7 52 : 54	24 Longueur de bras gauche / L. arm length 49.5 52.5 : 54

- Note 1 There were two manual measurements in '9, 11, 13-14, 18-19, and 22-23', the first measurement refers to taking from a human body standing in a natural stance, whereas the second refers to standing in the way which Symcad requires. In '10, 12 and 24', the second measurements refer to the measurement taking for the use of garment.
- 2 The measurements for sleeve and crotch lengths are taken the 'full length' (i.e. for garment use) into account.
- 3 The measured subject was taken only front and side views by the camera.
- 4 The Symcad used in this case was version 3.2. It was exhibited at the 'Tomorrow's World Live' event in the NEC, Birmingham, UK, dated 11-15 February 1998.



This picture was featured in the Tex-Data systems' brochure which was provided in the 'International Clothing Machine Fair', in Cologne, dated 3-7 Jun. 1997.



This picture was featured in Aldrich (1997, p.187) *Metric Pattern Cutting*, 3rd. edition (revised).

AGMS-3DCDI-DesignConcept 3D

Hardware : Engineering Work Station
(HP 9000 model 712/60)

* Processor :

-memory capacity 64 MB
32 bit RISC

-operation speed 73 MIPS

-operation system UNIX

* Magnetic Disk :

-disk capacity 1 GB

-disk type / size Floppy

Silicon Graphics

A2 Audio Processor :

128 MB

200 Mhz (CPU: MIPS 4400)

IRIX

SCSI -2020 MB

CDROM

DAT 4mm 1253 MB

The computation employs techniques, such as shading, mapping, render or raytracing to carry out static 3D image simulation.

Shading, is 'a method of displaying a surface's interior area that makes the surface appear solid' (CDI, 1995, p.GL-11). The shading, in the CDI's 3D software is defined into two types: the hardware shading and the software shading. The hardware shading refers to the spot lights which currently are provided by the hardware, whereas the software shading refers to providing a better-looking image using an unlimited number of lights (in reality, this requires more time to display). Nevertheless, 'the software shading allows the effects of spot lights to be displayed, even when hardware shading does not support spot lights' (CDI, 1995, p.'5-7').

Mapping, is also a shading process that applies 2D image to 3D model entities, so 'the mapped 2D images mold to model contours and blend with material properties' (CDI, 1995, p.GL-7).

Render, 'applies software shading to a displayed surface model or selection of a model' (CDI, 1995, p.'5-9'). The shaded image can then be saved as a permanent image file, e.g. the RGB image.

Raytracing, is a function which enables a 3D image to be created using 2D rendered image. The raytraced image is simulated in association with the lights, an existed rendered image file, the specification of the colour, texture and material properties.

'Regions' is the program which consists of several parameters (see pp.5-8~19) for flattening a curvilinear area from 3D to 2D. Amongst these parameters, 'Iterate' is the major process which triangular meshes are used as base knowledge for the software to recognise and estimate the transferring between a 3D curvilinear area to a 2D flat area.

The fundamental principle of 3D-2D electronic flattening is that, by means of distributing tension and compression to 'mesh links' (see Figure 5.2, p.5-5), software then iterates to minimise tension and compression¹. However, based upon this mathematical model, flattening speed and solution were the two major concerns which current software has not yet been programmed or completed perfectly, as stated by Shah²:

'since this is an iterative process, you may not reach the ultimate minimum'.

Reaching the ultimate minimum energy state may require an inordinate amount of computer time. And even if it did, there is no guarantee that the solution will be any better than if you only perform a certain number of optimisation iterations.

Current software provides two modes, i.e. flattening with or without inputting mechanical fabric properties, for users to flatten a 3D Region. If a 3D Region is flattened without the establishment of mechanical fabric properties, then *the software will try to minimise 'strain' and not 'stress'*. This shows that software has potential to produce a pattern in relation to different fabric properties.

Shah also clarified that flattening from the 'gravity point' (see p.5-14) of a 3D Region is not necessary the best method to obtain a 2D pattern with fit quality. Seow³ believed that flattening from the most convex point of a 3D pattern would reduce the stress and strain to a minimum. Shah suggested that more experiments can identify a better method for this.

¹ For further technical details, see CDI-3D software U.S. Patent number 5,107,444 and 5,448,687.

² Shah was one of the software programmers who was involved into the early development of current CDI-3D software (private contacts, dated 10 Sept. and 27~28 Oct. 1998).

³ Seow is currently researching 3D-2D flattening in the Hinds and McCartney's research group at the Queen's University in Belfast (private contacts, dated 8 May and 26~27 Oct. 1998).

Appendix 21 The nine cone surfaces flattened respectively with and without a cut

	Height / Radius	3D : 2D Area	%	3D : 2D Circumference	%	3D : 2D Cut Length	%
(without a cut)							
HAR12	0.33		98.75		96.81	x	x
HAR9	0.44		98.46		95.94	x	x
HAR6	0.67		99.49		91.04	x	x
HAR12	0.67		96.62		89.69	x	x
HAR9	0.89		97.10		87.11	x	x
HAR12	1.00		95.26		82.20	x	x
HAR6	1.33		101.75		77.94	x	x
HAR9	1.33		96.23		78.85	x	x
HAR6	2.00		x		x	x	x
(with a cut)							
HAR12-c	0.33		99.68		99.17	12.65 : 12.58 / 12.66	100.56 / 99.92
HAR9-c	0.44		99.98		99.92	10.77 : 10.77 / 10.76	100.00 / 100.09
HAR6-c	0.67		99.79		98.40	7.21 : 7.10 / 7.17	101.55 / 100.56
HAR12-c	0.67		100.01		100.00	14.42 : 14.42 / 14.42	100.00 / 100.00
HAR9-c	0.89		99.99		99.95	12.81 : 12.80 / 12.79	100.08 / 100.16
HAR12-c	1.00		98.93		96.23	16.97 : 16.16 / 16.75	105.01 / 101.31
HAR6-c	1.33		100.06		99.97	10.00 : 10.00 / 9.98	100.00 / 100.20
HAR9-c	1.33		x		x	x	x
HAR6-c	2.00		x		x	x	x

Note: the 'H' refers to height, the 'R' refers to radius, and the 'c' refers to a cut.

Appendix 22 The nine spherical surfaces flattened respectively with and without a cut

	Height / L _{ms}	3D : 2D Area	%	3D : 2D Circumference	%	3D : 2D Cmk Length	%
(without a cut)							
H2L4.5	0.44	75.30 : 75.17	100.17	28.10 : 30.77	91.32	x	x
H4L9	0.44	304.98 : 310.10	98.35	56.46 : 62.44	90.42	x	x
H6L13.4	0.45	680.49 : 698.39	97.44	84.40 : 93.69	90.08	x	x
H4L5.6	0.71	148.74 : 148.53	100.54	35.42 : 43.24	81.91	x	x
H8L11.3	0.71	604.44 : 628.62	96.15	71.12 : 88.90	80.00	x	x
H12L17	0.71	1352.04 : 1424.15	94.93	106.53 : 133.79	79.62	x	x
H6L6	1.00	225.52 : 218.23	103.24	37.67 : 52.40	71.89	x	x
H12L12	1.00	902.19 : 940.31	96.59	75.39 : 108.74	69.33	x	x
H18L18	1.00	2034.96 : 2165.85	93.96	113.09 : 165.00	68.34	x	x
(with a half cut)							
H2L4.5-hc	0.44	75.30 : 74.91	100.52	28.10 : 29.56	95.06	5.05 : 5.04 / 5.14	100.20 / 98.25
H4L9-hc	0.44	304.99 : 307.68	99.13	56.46 : 60.64	93.11	10.16 : 10.12 / 10.50	100.40 / 96.76
H6L13.4-hc	0.45	680.48 : 691.37	98.42	84.40 : 91.23	92.51	15.18 : 15.70 / 15.05	96.69 / 100.86
H4L5.6-hc	0.71	148.76 : 148.65	100.07	35.42 : 41.18	86.01	7.32 : 7.62 / 7.33	96.06 / 99.86
H8L11.3-hc	0.71	604.43 : 615.38	98.19	71.12 : 83.20	85.48	14.80 : 14.51 / 15.38	102.00 / 96.23
H12L17-hc	0.71	1352.01 : 1403.80	96.17	106.53 : 127.24	83.72	22.12 : 21.95 / 23.34	100.77 / 94.77
H6L6-hc	1.00	225.52 : 218.76	103.00	37.67 : 47.71	78.96	9.42 : 10.21 / 9.32	92.26 / 101.07
H12L12-hc	1.00	902.17 : 916.40	98.45	75.38 : 99.38	75.85	18.84 : 18.47 / 20.64	103.00 / 91.28
H18L18-hc	1.00	2034.96 : 2117.06	96.12	113.09 : 152.11	74.35	28.26 : 27.76 / 30.98	101.80 / 91.32

Note: the 'H' refers to height, the 'L' refers to the depth level of the spherical surface, and the 'c' refers to a cut.

Appendix 23 The nine spherical surfaces flattened with one full cut

	Height : Line	3D : 2D Area	%	3D : 2D Circumference	%	3D : 2D Cut Length (c)	%
(with 1 full cut)							
H2L4.5-fc	0.44	75.30 : 75.01	100.39	28.10 : 28.96	97.03	10.10 : 10.28 / 10.36	98.25 / 97.49
H4L9-fc	0.44	304.98 : 305.02	99.99	56.46 : 58.22	96.98	20.32 : 20.89 / 20.89	97.27 / 97.27
H6L13.4-fc	0.45	680.48 : 682.17	99.75	84.40 : 87.30	96.68	30.33 : 31.16 / 31.13	97.34 / 97.43
H4L5.6-fc	0.71	148.75 : 147.81	100.64	35.42 : 37.61	94.18	14.67 : 15.44 / 15.55	95.01 / 94.34
H8L11.3-fc	0.71	604.42 : 604.98	99.91	71.12 : 75.77	93.86	29.58 : 31.49 / 31.35	94.11 / 94.35
H12L17-fc	0.71	1352.01 : 1362.36	99.24	106.53 : 114.06	93.40	44.22 : 47.05 / 46.90	93.99 / 94.29
H6L6-fc	1.00	225.31 : 221.99	101.50	37.67 : 41.08	91.41	18.84 : 20.87 / 20.58	90.49 / 91.55
H12L12-fc	1.00	902.18 : 902.12	100.01	75.39 : 83.27	90.54	37.69 : 41.63 / 41.34	90.54 / 91.17
H18L18-fc	1.00	2034.95 : 2038.08	99.88	113.09 : 123.13	90.38	56.54 : 62.37 / 62.56	90.65 / 90.38

Note: the 'H' refers to height, the 'L' refers to the depth level of the spherical surface, and the 'fc' refers to one full cut.

Appendix 24 The nine spherical surfaces flattened with two cuts

	Height : Line	3D : 2D Area	%	3D : 2D Circumference	%	3D : 2D Cut Length (G)	%
(with 2 cuts)							
H2L4.5-2c	0.44	75.29 : 74.94	100.47	28.10 : 29.07	96.66	5.05 : 5.18 / 5.10 : 5.05 : 5.07 / 5.11	97.49 / 99.02 : 99.61 / 98.83
H2L5-2c	0.44	304.99 : 306.24	99.59	56.46 : 59.53	94.84	10.18 : 10.12 / 10.34 : 10.16 : 10.42 / 10.29	100.59 / 98.45 : 97.50 / 98.74
H2L13.4-2c	0.45	680.48 : 684.61	99.40	83.40 : 88.33	94.42	15.18 : 15.39 / 15.40 : 15.16 : 15.45 / 15.37	98.64 / 98.57 : 98.12 / 98.63
H4L5.6-2c	0.71	148.74 : 147.61	100.77	35.42 : 39.03	90.75	7.33 : 7.61 / 7.50 : 7.32 : 7.25 / 7.55	96.32 / 97.73 : 106.62 / 96.95
H8L11.5-2c	0.71	604.42 : 608.18	99.38	71.12 : 80.16	88.72	14.85 : 14.52 / 15.27 : 14.80 : 15.64 / 15.27	102.27 / 97.25 : 94.37 / 96.92
H12L17-2c	0.71	1352.01 : 1367.98	98.83	106.53 : 116.39	91.53	22.11 : 23.25 / 22.82 : 22.12 : 23.04 / 22.78	95.10 / 96.89 : 96.01 / 97.10
H2L6-2c	1.00	225.31 : 221.85	101.56	37.67 : 43.46	86.68	9.40 : 10.25 / 9.81 : 9.42 : 9.59 / 9.86	97.82 / 95.82 : 96.23 / 95.54
H12L12-2c	1.00	902.15 : 903.51	99.85	75.39 : 87.28	86.38	18.89 : 19.82 / 19.85 : 18.84 : 20.94 / 19.76	95.31 / 95.16 : 89.97 / 95.34
H18L28-2c	1.00	2034.94 : 2077.74	97.94	113.09 : 126.41	82.90	28.26 : 31.11 / 29.85 : 28.32 : 28.50 / 29.84	90.84 / 94.67 : 99.37 / 94.91

Note: the 'H' refers to height, the 'L' refers to the depth level of the spherical surface, and the '2c' refers to two cuts.

Glossary

2D to 3D	a process to 'wrap'; also named 'drape' (see pp.3-63~67).
3D to 2D	a process to flatten, i.e. 'unwrap'.
AAMA	abbreviation of 'American Apparel Manufacturers Association'.
AccuMark	this is a brand of a series of 2D pattern design systems from Gerber Technologies Ltd. (previously Gerber Garment Technology).
ASCII format	a file format employed by the CDI-3D system to interpret a 3D form in accordance with the digitised 3D data, i.e. data points in (x, y, z) co-ordinates.
Block	a basic garment pattern (see Appendix 9, p.A-9).
CAD	'computer aided design'.
CBACK	centre back pattern piece.
CDS	'concept design system', which is based on using raster to paint an image.
CFRONT	Centre front pattern piece.
Contact-fit	a 'skin-tight' fitting type, i.e. theoretically, no ease exists between the fabric and the form surface (this is a term which is invented specifically for use in this study, see also p.3-64).
Contact-fit toiling	a manual toiling process, specifically from 'moulding' to 'skinning-off' the created sample garment form using paper or calico i.e. theoretically, paper or calico contact-fits on the solid garment form (see p.4-39).
Compression	a negative percentage of the force which occurs when transferring a surface between 3D and 2D; this is in contrast to 'tension'.
<i>CURVES</i>	one of the CDI-3D programs which enables curved lines to be drawn and recognised in the CAD environment (see p.3-65).
DAT	the abbreviation of 'digital audio tape', which has a similar function as a floppy disk but for larger quantities of off-line data storage.

Pattern discrepancy tolerance	a tolerance for any inconsistency when transferring a surface between 3D and 2D.
<i>DEVELOP</i>	one of the CDI-3D's programs which enables a 3D pattern area and pattern edges to be created with some distortion so it can be calculated mathematically.
Dual bending	the two bending directions are constructed at a right angle to each other (see p.4-41).
.DXF	standard AutoCAD file format.
Dynamic fit	an instinctively visual and sensual response to a body which is conditionally accepted by the observers (see p.2-56).
Edge-matched flattening	the process is similar to the 'Standard' flattening, except when selecting the 'Edge' matched function before flattening. The flattened 2D pattern edge measurements will be identical to a 3D pattern's edge (see p.5-34).
FAST	'Fabric Assurance by Simple Testing'; a method to assess fabric tailorability (see p.4-40).
FEA	'finite element analysis'; a model which 'divides the surface of a piece of fabric into a grid and then mathematically figures the curvature of the surface based on the qualities of the particular fabric in question' (Nannery, 1996).
<i>FINAL</i>	a function in one of CDI-3D programs to stabilise mesh layers by minimising the tension and compression through meshes (see p.5-19).
Garment form	a substantially solid 3D garment (i.e. including <i>solid</i> garment eases between the human body and the fabric) in the real and virtual worlds.
Grading rules	a table of figures which indicates increasing or decreasing values of the (x, y) direction at each identified point of a pattern. After reconnecting all the new associated points, different sizes of a garment can be produced accordingly.

Grain	the direction which is in parallel with the warp thread of the fabric.
<i>GRAIN</i>	one of the CDI-3D functions which deals with the indication of an electronically developed pattern in the 'Regions' program.
Gravity point	The 'gravity point' is a particular mesh node on a triangular-mesh-generated 3D pattern; the 3D electronic flattening is programmed to reduce pattern distortion to minimum by selecting this point to begin flattening (see p.5-14).
IGES	'Initial Graphics Exchange Specification'.
<i>ITERATE</i>	a count control of the flattening process in the CDI-3D system (see p.5-19).
KES	'Kawabata Evaluation System' for fabric (see p.3-61); an objective fabric testing method.
<i>KEYMARKS</i>	one of the CDI-3D functions which deals with making marks on an electronically developed pattern in the 'Regions' program (it works as 'notches' in the current CDI-3D system).
Landmarks	the marks which are used on a net body in order that body measurements for garment pattern construction can be obtained.
LASS	abbreviation of the 'Loughborough Anthropometric Shadow Scanner' (it is identified as a 3D non-contact digitiser in this study).
<i>LAYER</i>	a function of generating new mesh layers in the CDI-3D 'Iterate' program (see p.5-19).
Made-to-measure	in manual pattern cutting, a cutting method which is meant to cut a pattern to fit an individual body rather than a standard size; in a virtual world, a 'Made-to-measure system' adapts the same principle (see pp.3-40 and 3-52).
Mesh link length	the triangular mesh size which is used to recognise and generate a '3D Region' in the CDI-3D system (see p.5-11).
Mesh node	is a node point which is an intersection of mesh links (see Figure 5.1 and p.5-14).
Mirror	a process to produce symmetry by flipping vertically or horizontally; i.e. along the 'Y' or 'X' axis.

Net bodice block	a block which smoothes the concave areas of the bodice (e.g. between bust points and blades), simplifies the complex bodice curvatures, and is 'contact-fit' to the bodice (see pp.2-53~54).
Notches	the marks which are made on a paper or fabric garment pattern to assist in checking accuracy or in manufacturing assemblies.
NURBS	abbreviation of 'non-uniform rational B-spline'; a mathematical method of dealing with curved lines in a CAD environment.
Pattern	a garment piece which is produced by adapting a basic block or creating directly from a design sketch using sheet paper or fabric (see also Appendix 9, p.A-9).
Pattern validation	an process to assess a garment pattern for use in production (see p.2-68).
PDS	abbreviation of 'pattern design system', which is based on using vector to construct lines.
Raster	'Raster images' are created using dots or 'picture elements' (pixel); each pixel (not mathematically based) can be lit up independently to assemble multi-coloured imagery.
<i>REGIONS</i>	one of the CDI-3D programs which enables a 3D surface to be recognised and calculated while it is transferred to a 2D pattern (see p.3-65).
ROM	abbreviation of 'Read Only Memory'; it contains a piece of software or program, so as not to lose their contents when the the computer is switched off.
SBACK	side back pattern piece.
SFRONT	side front pattern piece.
Single bending	simple curvature which occurs in one single direction e.g. a cone or a cylinder.
Size charts	the tables which consist of body measurements (usually size coded) for use in making garments.
Sizing	a process of classifying bodies or garment dimensions.
Standard flattening	a process to flatten a pattern in the CDI-3D system from 3D to 2D (see p.5-34).

Static fit	a measure of the relationship of the motionless human body or garment stand and the garment (see p.2-56).
Structured modelling	this refers to the creation of a garment to fit a body form; its contrast is 'non-structured' modelling (see p.2-37 and 2-45).
Suppression	the controlling of garment ease on a garment pattern, i.e. a garment pattern cutting method which takes off excess materials in order to produce a form which conforms to an individually required fit quality in relation to a human body and a garment form (the waist suppression is a typical term for this).
'Surface' boundary	an edge of a 'Surface' which is generated using the CDI-3D system; importantly, this is not equal to a pattern edge because the characteristics of a 'pattern' is interpreted by the 'Regions' program.
Surface display precision	the smoothness parameter of a generated Surface in the CDI-3D system (see p.5-8).
<i>SURFACES</i>	one of the CDI-3D programs which can control a 3D form by reducing thousands of digitised data points to a minimum; also it allows garment style lines to be constructed on it.
Tension	a positive percentage of the force which occurs when transferring a surface between 3D and 2D; this is in contrast to 'compression'.
Toiling	a manual method of constructing a garment pattern in three dimensions by manipulating fabric over a garment stand or a human body.
<i>TOTAL</i>	one of the functions in the CDI-3D 'Iterate' program which is to distribute and balance the existing mesh layers in the 'Regions' flattening process (see p.5-19).
<i>TRANSLATOR</i>	one of the CDI-3D programs which enables CDI electronically flattened pattern data to be translated to another type of pattern data, e.g. AccuMark or AAMA format (see p.4-54).
UNIX	Computer operating system as used by Silicon Graphics.

<i>UTILITIES</i>	one of the AccuMark's programs which enables pattern data to be copied, deleted, imported, exported (see p.4-56).
UV Curve	one of the curve types which is used to construct a style line on one 'Surface' in the CDI-3D system, based on curvilinear co-ordinates (U, V) as opposed to rectangular or Cartesian co-ordinates (see p.5-37).
UV meshes	a collection of surface patch boundaries (for detailed illustration, see pp.4-25~30).
Vector	vector images are produced by points and line segments; vector technology is mathematically based, in contrast to raster which is Pixel (picture element) based.
<i>Wireframes</i>	one of the CDI-3D's programs which enables thousands of digitised data points to be built up as a 3D framework.