Loose fitting garments can accommodate a greater number of different body shapes but close fitting garments cannot. The assumption is that stretch garments will automatically stretch in the right places to give an acceptable fit and provide comfort as well as ease of movement. But this is a fundamental misunderstanding of stretch fabric characteristics and garment pattern geometry. To date the garment industry has focused on speeding up, through the use of CAD systems, empirical pattern construction methods which developed through custom and practice. This subjective approach has significant limitations, particularly when applied to stretch pattern design it is inappropriate for today’s technology. A brief overview of current pattern technology has been presented in this paper. The factors considered in developing stretch pattern technology include digitally quantifying the degree of fabric stretch and an objective approach for assessing stretch fit. The aim of the study is to make the process of stretch pattern construction more transparent in CAD applications for the designer/technician, fabric technologist and global manufacturer, and ultimately to offer better fitting and more comfortable garments for the customer.

Keywords: Close fitting garments, Digital fashion design, Pressure garments, Stretch pattern design

1 Introduction

Elastane was developed in mid 20th century as a replacement for rubber in corsetry. Increasingly the inherent benefits of stretch to comfort and mobility are utilised in high proportion for applications particularly those which closely contour the body. Stretch fabrics are also a major component of the functional clothing industry. However, the understanding of how to optimise the stretch potential in pattern design is, in relative terms, still in its infancy. Comprehensive study detailing all aspects of an objective approach to stretch pattern development has not been done so far.

The development of an objective approach to stretch pattern technology is the focus of this study. I believe that a good fitting basic block pattern that replicates the body contour shape and an understanding of the behaviour of stretch characteristics for pattern construction are vital for maximising the benefits of new technologies, whatever is the application. In garments with conventional pattern co-ordinates, the looser the fit means that a greater number of body shape anomalies can be accommodated. Conversely, irrespective of the number of girth and length measurements, the tighter a garment the greater is the garment-to-body fit disparity. This curvilinear distortion of the stretch fabric is not always apparent, as some inconsistencies can be absorbed within the stretch fabric behaviour.

According to a survey undertaken by Kurt Solomon Associates1, 70% of women say that they still have difficulty in finding clothes that fit well. Kim and Damhorst2 highlight that concerns with fit and size are particularly relevant for online purchase intentions. Size designations give no indication of the garment-to-body fit relationship or any clue as to the intended body shape of the target consumer. Women may have similar circumferential measurements but can be vastly different in body shape, proportions and postures.

Conventional non-stretch pattern construction systems have an in-built ease allowance. Ease (tolerance) is the allowance of a certain amount of fabric on a woven block pattern, which allows movement; involuntary such as breathing or voluntary like sitting down. It can be extremely difficult to determine the mathematical relationship between the amount of ease applied in the pattern profile and the actual body measurements. Therefore, the garment-to-body fit relationship is arbitrary which poses difficulties for assessing fit objectively. In general, garment design/style fit is left to the individual to interpret the acceptability of how closely the garment conforms to the body. The use of the term ‘fit’ in the context of my research in stretch pattern design development is the proximity of the garment to the...
body and the fabric stretch parameters, which is explained more extensively in this paper (section 4.1).

2 Stretch Pattern Construction

Stretch garments are constructed by using a pattern that has a negative ease value. In other words, the pattern is cut to body dimensions smaller than the actual body. It is the inherent fabric stretch which ultimately determines the finished garments size designation.

Conventional pattern profiles for stretch fabrics have been developed by modifying block patterns for woven fabrics that have the ease allowance and darts removed. Difficulties arise in determining the amount and location of the ease allowance to be removed. Darts are used to contour the fabric around the body form smoothly without the fabric buckling. The placement of darts and the amount of fabric suppression vary between block patterns. In a typical front bodice, the dart is suppressed (closed), removing it completely from the bust area, all or a proportion the dart is then redistributing at the bodice shoulder or side seam. After the block pattern has the ease allowance and darts removed, the profile is then trued into smooth lines and fluid curves. When this procedure has been completed the pattern profile is proportionately reduced horizontally and vertically to accommodate a fabric stretch percentage. Conventionally, calculation of the stretch percentage is very subjective. Another approach for producing a stretch pattern is to model the stretch fabric directly onto a dress stand. But this method is also subjective as it is difficult to determine how much hand stretch (force) is being used to achieve the desired pattern design. Some manufacturers just use a smaller sized pattern block with the assumption that the stretch fabric will automatically stretch in the right places to give an acceptable fit. These highly subjective approaches do not maximise the stretch fabric potential to provide a good fit quality.

The ability to predict how closely stretch fabric should conform to the body for optimum performance and comfort levels is vital in stretch garment research. Harada explored the relationship between the degree of skin stretch and the degree of fabric stretch in conjunction with the proximity of the garment to the body. They utilised Laplace’ law \( P = T/\rho \), where \( P \) is the pressure exerted on the body, \( T \) is the tension of the fabric which is dependent on stretch parameters, and \( \rho \) is the radius of the curved surface of the body. Assuming that the degree of fabric stretch is maintained at a constant level, the tension in the fabric will remain constant. A key variable affecting the pressure of the fabric on the body is therefore the radius of the part being covered, the smaller the curve the higher is the exerted pressure. The implication of this is that the amount of pressure applied along the leg, for example, would not be linear. Parts with smaller radii (e.g. ankles and wrists) require less reduction in the fabric to achieve the same garment-to-body interface pressure.

2.1 Subjectivity in Stretch Pattern Development

Stretch fabrics are increasingly being used across the whole gamut of clothing applications, such as fashion, sportswear, intimate bodywear, medical and functional garments. To date textbooks that instruct the users on how to design stretch patterns just reiterate subjective practices that date from the 1960s. Pratt and West in their manual ‘Pressure Garments: a Manual on their Design and Fabrication’ suggest a mathematical formula for pattern drafting. Basically, all circumferential measurements are reduced by 20% and length measurements are reduced typically by 20-25% of their total length. But they go on to state that applying the formula is not straightforward and needs subjective adjustment based on experience. Shoben, in his introduction to ‘The Essential Guide to Stretch Pattern Cutting’, suggests that pattern cutting is not a science but an art and that dealing with stretch fabrics is a minefield, because the almost unlimited variations in their composition makes the sizing of patterns extremely difficult.

3 Stretch Fabric Extensibility

If a non-stretch woven fabric is stretched in one bias (diagonal) direction it generally contracts almost as much in the other direction. The same applies for a stretch fabric. The stretch fabric also contracts in the opposite direction when stretched laterally. This effect is enhanced in the knit fabric because of its more malleable structure. The effect of bias stretch has significant implication for stretch contoured pattern profile geometry.

3.1 Woven Stretch Fabrics

Lindberg, a Norwegian textile scientist, conducted research into how woven stretch fabrics perform. The purpose was to assess how great the stretchability of the fabric should be to provide reasonable comfort. He examined the interplay between the characteristics of the fabric and garment
construction and the body. The maximum increase in fabric distortion and the distance between various restraint points (neck, shoulder, armpits, crutch, hips, seat and knees) subject to different body measurements, like crouching were recorded. He found that the fabric never stretched proportionally between two points. The grip points in a crouching position (hips, seat and knees) form a complicated mechanical system. This was observed by drawing a series of circles with a known diameter with lines indicating the warp and the weft. When the body was mobilised the circle became elliptical, and the direction of the greatest stretch was indicated by the direction in which the ellipse had its major axis. It was possible to calculate the amount and direction of stretch at particular points on the garment, where simultaneous stretch occurs.

3.2 Knit Stretch Fabrics

The available literature on stretch pattern design is found to be inconsistent with regard to sample width, length and forces needed to quantify the degree of stretch extension \(^\text{3,8,10}\), which is extremely confusing for the designer. Ziegert and Keil \(^\text{12}\) used a measurement unit of 20 cm × 20 cm with a 500 g load. The rationale for the test unit size was related closely to one-quarter human body dimension of garments made with elastomers. However, Murden \(^\text{13}\) suggested that a good approximation of the hand stretch could be achieved mechanically by taking a measurement unit of 7.5 cm × 25 cm with a load approximating 1 kg/cm. Because of this confusion an understanding of fabric stretch and extension characteristics was required. Therefore, exploratory mechanical force extension testing was undertaken using the Instron tensile testing apparatus to identify the forces involved in stretch fabric extension in the course, wale and bias.

3.3 Instron Force/Extension Testing

The Instron tensile testing machine is used extensively to electronically calculate the extensibility of a variety of sample materials. Several standards \(^\text{14-16}\) (BS 4952:1992; BS EN 14704-1:2005; ASTM D 4964-96:1996) highlight a number of specific tests for quality assurance (QA) and quality control (QC) for stretch fabric but they are not suited for assessing the degree of fabric stretch required for garment pattern geometry.

The overall aim and objectives was to record and plot electronically the force/extension characteristics for a range of fabric samples that have been cut in the course, wale and bias directions, to analyse the effect that fabric orientation has on the load/extension curve of a given sample, to compare the different samples for a given fabric orientation, to identify typical working ranges for the sample fabrics and to ascertain an optimum loading for a fixed load test.

The fabric sample chosen covered a range of weights and elastane content which exhibited different bi-directional stretch characteristics and were selected because of their general suitability for a broad range of stretch performance wear. The fabric samples coded A, B, C, D and E are detailed in Table 1. The fabrics A-E were cut in the course (c), wale (w) and bias (b) directions with three sets of each orientation. The samples had a width of 5cm and were benchmarked with 2 parallel lines placed 10cm apart. All samples were subject to specific pre-test conditioning. Following the standard Instron testing procedure the fabric samples were clamped between the metal jaws taking care to remove excess slack material. The Instron was set up for a simple non-cyclic test. The sample was loaded until an extension of 100% was reached. The force required was recorded at 1mm intervals for each loading. The stretch/loading characteristics were recorded using the standard Instron program. The data was then imported into a spreadsheet allowing ease of analysis.

3.3.1 Fabric Sample Orientation

The resulting plot for sample A, for instance, is an average of samples A1, A2 and A3 but is displayed over a typical working range of less than 60% stretch as opposed to the full tensile testing range of 200%. The force stretch curves for samples A1, A2 and A3 and an average of sample A are shown in Fig. 1. Samples B, C and D were characteristically similar.

There is a marked difference in the extensibility between fabric orientations for a given sample. At the higher levels of stretch, the wale offers the least resistance to stretch and the course offers the greatest. However, for lower values of stretch, the reverse is true, where the course offers the least resistance, which is more representative of the stretch extension working range of stretch garments.

3.3.2 Fabric Sample Correlation

Figure 2 shows the correlation among samples A-D for the course, wale and bias orientations respectively. For a given orientation, there is a good
correlation between samples, suggesting that the fabric behaviour could be consistent within a required working range. The wale force/stretch curves, at first sight, again suggest that this orientation offers the least resistance to stretch.

3.3.3 Stretch Extension Working Range

Figure 3 shows the stretch extension working ranges of up to 60% stretch. Denton\textsuperscript{17} looked at the relationship between fit, stretch, comfort and movement. It was ascertained that in the seat area of
various garments, the actual fabric stretch of the garment, in wear, was considerably less than the maximum available fabric stretch percentage. The results of the Instron testing clearly illustrated that the wear range is within the lower working range, where the course orientation offers the least resistance. The bias orientation also requires lower forces than the wale direction, which is significant when determining the amount of the available fabric stretch to be used in the reduction algorithm applied to the pattern geometry.

It was expected that the extensibility in the wale direction would be greater than in course. This was indeed the impression gained from experience and clearly demonstrated by the results of the hanger load tests reported by Ziegert and Keil\textsuperscript{12}. However, although this was true when stretching each of the test fabrics up to the test limit, while observing the useful working range of up to 30-40%, it was the course direction that clearly offered the least resistance and therefore had the greatest stretch. The main observation was that the stretch characteristics were not only non-linear, as expected, but were also inverted (the course showed greater extensibility than the wale) in the crucial stretch extension working range. This has significant implications for the pattern orientation and profile geometry.

However, the designer and pattern technologist require a more readily accessible method to estimate the degree of stretch, and the results suggested that a simple load test applying a fixed weight of 250 g to a prepared sample width of 5 cm could be employed.

### 3.4 New ‘Quad Load’ Stretch Extension Test

Literature on testing the degree of fabric stretch extension for garment pattern reduction is inconclusive on test fabric size, loading and application. Until an industry standard has been established, it is essential that the designer can follow a simple method to calculate the degree of stretch, which offers consistent results without requiring specially controlled conditions. These results should ideally show a breakdown of fabric extension into course, wale and bias (45° and 135°), which can be used to calculate the relative stretch reduction factor. The author used an adapted hanger load-test, referred to as ‘quad load test method’, designed specifically to digitally quantify fabric extension for use as part of the stretch block pattern reduction procedure as outlined by Watkins\textsuperscript{18}. The aim and objectives were to calculate the degree of stretch extension at a specific load of 250 g for sample fabrics in the four orientations of course, wale and bias (45° and 135°).

Sets of 4 for each of the 5 sample fabrics (Table 1) were cut into strips measuring 5 cm × 20 cm in the course, wale and bias orientation. The test samples were identified for example as sample ‘AC’ for fabric A cut in the course direction.

Figure 4 shows the fabric pattern, illustrated as a 5 cm × 20 cm rectangle, with benchmarks on 10 cm centres between which the extended length was measured. A 2.5 cm fold at both ends was machined, forming slots ready for the insertion of the hanger supports. In the quad load test procedure, fabric samples in the course, wale, 45° bias and 135° bias were placed on the hanger and the 250 g weight was applied. After allowing one minute for the fabric to stabilise, the extended measurement between the benchmarks was recorded (Table 2).

The benchmark relaxed length of 10 cm was chosen because the calculation of the degree of stretch is simplified. The degree of stretch expressed as a
percentage is calculated by subtracting the relaxed length from the extended length and then dividing the result by the original length or simply by subtracting 10 cm (100 mm), from the extended length.

Degree of stretch = \([\text{Extended length (mm)} - 100] \%)\]

For example, in case of course fabric B (coded BC)

Degree of stretch = \((156 - 100) \%) = 56\%\)

3.4.1 Stretch Distribution Quad Angle Plots

Entering the test results into a spreadsheet enabled a graphic representation of the distribution of stretchability throughout 360° of fabric orientation to be displayed. This method was adapted from Lindberg\(^1\) which was used to compare the bias stretch in woven double or bi-directional stretch and a non-stretch fabric.

Although only three measurements were taken for each fabric corresponding to 0°, 45° and 90° rotation, it was assumed that inverse symmetry would apply. However, fitting experimental garments led to questioning the use of a single bias extension...
measurement only, because a fit disparity was observed between the right and left side of the evaluation garments. Subsequently, it was found that not all stretch knit fabrics had a corresponding degree of stretch between the bias at 45° and at 135° (Table 2). The quad angle plots for A B C D and E samples (Figs 5 a-e respectively) compare the angular stretch distribution curves for the single 45° bias and double 45° and 135° bias measurements.

If a fabric were to behave as a simple lattice structure that had very limited stretch in the course and wale directions, the resulting stretch distribution curve would be represented by four vectors radiating from a central point. A stretch distribution plot of a fabric that extends uniformly in all directions for a given load would be circular. All the angular stretch distribution plots clearly demonstrate that the highest stretch is in the course direction. Samples B, C and D show vertical symmetry. Samples A and E demonstrate a lack of symmetry in the bias stretch. These plots made a significant contribution to my understanding of stretch fabric characteristics, the impact of bias stretch on pattern profile geometry and the optimal pattern orientation for dynamic fit. The results indicate that to achieve a consistent contour fit, garment right and left sides require an equal bias measurement. Although small differences can be absorbed because of the stretch fabric characteristics this may not always be appropriate. In compressive garment technology, particularly in medical applications, an equal bias measurement may be crucial to get an equal pressure on the body between right and left sides.

3.5 Digital Stretch Pattern Technology

The new quad load test provides the input data for the fabric course, wale, 45° bias and 135° bias stretch extension and is readily accessible to the designer/pattern technologist. Because it does not rely on complicated scientific apparatus or a controlled environment, it is a convenient and simple method of quantifying stretch extension. This method does not attempt to replicate British Standard test conditions in a controlled environment and therefore some minor inconsistencies may occur. The multi-directional stretch fabric extension has to be applied on the 2D pattern pieces using just two measurements on the x and y axis. The bias extension is the average between the course and the wale becoming the course/bias and the wale/bias extension measurements referred to as bias vectors.

Fig. 5—Angular stretch distribution curves for different samples
Movement in any area of the body has to be accommodated by utilising available fabric stretch and generally must be greater than free body expansion. Therefore, the length of the body to accommodate maximum elongation will require the fabric to be reduced by a different proportion to the circumference of the body, which is not subject to the same movement excesses. I refer to this variable as the axis ratio.

When reducing patterns for children, a tension release factor (TRF) was introduced, which is expressed as a per unit value of 1 for adults reducing down to 0.5 for young children. The TRF accommodates the radius of curvature resistance to pressure (section 2). Garments constructed for a variety of applications will require differing fit levels as outlined in section 4.1. The fit factor variable allows different fit level categories to be accommodated. The reduction factor takes an amount of the available stretch for the appropriate fit level. This fit factor then determines the amount of the available stretch to be applied by the axis ratio, which is the allocation of the amount of available stretch by different proportions to the vertical and horizontal pattern profile.

3.5.1 Pattern Reduction Method

The quad load test gives us the available fabric stretch (FS%) in the course, wale and bias directions. For 2D pattern construction I express the effect that bias stretch has on the x and y axis values as the course-bias and wale-bias respectively.

For example, in case of Fabric B (Table 2), fabric stretch values in course (FSc), wales (FSw) and bias (FSb) orientations are given below:

FSc = 56%
FSw = 20%
FSb = 40%

Fabric Bias Vector %

In this exercise an average has been taken of the coarse & bias and wale & bias extension measurements. The examples of the course-bias vector (cb) and the wale-bias (wb) vector with the calculation using the above values are given below:

Course-bias vector (cb), % = (c% + b%) / 2

For sample B
cb, % = (56 + 40) / 2 = 48

Wale-bias vector (wb), % = (w% + b%) / 2

For sample B
wb, % = (20 + 40) / 2 = 30

Axis Ratio %

The axis ratio (AR) determines the way in which the garment pattern profile is reduced. In this exercise, the ratio is for an adult and experience would suggest a ratio of girth 60% to length 40%. More of the available stretch is needed in the length (ARc = 60%) of the garment than in width (ARw = 40%), so the reduction is less in the length.

Tension Release Factor

Tension release factor (TRF) is expressed as a per unit value of 1 for adults reducing down to 0.5 for small children.

Tension release factor: TRFc (course) = 1, TRFw (wale) = 1

Taking the TRF into account, AR would be

\[
\text{ART} \% = \text{Tension release factor} \times \text{Axis ratio} \% = \text{TRF} \times \text{AR}
\]

\[
\text{ARTc} \% = 1 \times 60 = 60
\]

\[
\text{ARTw} \% = 1 \times 40 = 40
\]

Stretch Reduction %

The stretch reduction (SR%) defines the percentage by which the pattern is to be reduced. It can be calculated for both course and bias directions using the following relationship:

\[
\text{SR} \% = \frac{\text{Fabric stretch} \% \times \text{Axis ratio} \%}{100}
\]

\[
\text{SRc} \% = \frac{(48 \times 60)}{100} = 28.8
\]

\[
\text{SRw} \% = \frac{(30 \times 40)}{100} = 12.0
\]

Stretch Reduction Factor

The stretch reduction factor (SRF) is expressed as a per unit multiplier value. It can be calculated for both course and bias directions using the following relationship:

\[
\text{Stretch reduction factor} (\text{SRF}) = \frac{100}{100 + \text{Stretch reduction}}
\]

\[
\text{SRFc} = 100/ (100+28.8) = 100/128.8 = 0.78
\]

\[
\text{SRFw} = 100/ (100+12.0) = 100/112.0 = 0.89
\]

The pattern profile may now be repositioned by multiplying, in this example, the X co-ordinates by 0.78 and the Y co-ordinates by 0.89.
4 Fit and Stretch Garments
Garment fit expectations are not always clear, particularly in relation to stretch garments.

4.1 Distal and Proximal Fit
To aid clarity, the anatomical terms proximal and distal fit have been introduced, which describe the proximity of the garment to the body on a proximal distal fit continuum with the body contour as the zero proximal reference point. As one moves away from the Form Fit (zero) reference point then the proximal (negative) value becomes greater, as the garment compresses the body. Conversely, in the distal (positive) direction, the garment fit becomes looser. For clarity garment fit has been approximated into three values either side of the zero point along the proximal distal fit continuum. Garments along the distal continuum away from the Form Fit describe garments that are constructed from fabrics which are either non-stretch or have minimal stretch to enhance comfort. These garments are essentially an external structure ranging from Fitted (D2) through Semi-fitted (D4) to a Loose fit (D6). The proximal fit describes body-contouring garments constructed in a stretch knit fabric. The increasing negative proximal fit is related to the garment pattern reduction ratio, influenced by the force exerted on the body, through the modulus or compressive retracting power of the stretch fabric. The proximal fit attributes are as follows:

- **Form Fit (P0)** describes garments that have few wrinkles and no stretch other than tare stretch (a minimal amount) in specific areas of protrusion, to allow the fabric to smoothly contour the body. The stretch fabric exerts no pressure on the body and the stretch does not impede mobility. An example would be close fitting underwear with no holding power.
- **Cling Fit (P2)** includes fashion garments where the fabric stretch does not significantly compress or alter the body contour. The stretch fabric clings to the body curves accentuating the natural shape, for example stretch T-shirts.
- **Action Fit (P4)** describes garments where the retracting stretch effectively grips the body. Most stretch sportswear and exercise garments come under this heading and are produced in a diverse range of knit fabrics with differing degrees of stretch.

- **Power Fit (P6)** refers either to the garment as a whole or to specific areas where the force exerted by the stretch holds and compresses the flesh, changing the body form shape. Applications cover a wide range of sportswear, form persuasive bodywear and medical applications.

4.2 Fit to Enhance Comfort and Movement
The analysis of traditional garment pattern design and fit for non-stretch fabrics, the method and the rational can stimulate imaginative solutions to enhance movement in stretch garment pattern design. Stretch garment analysis is also interpretive as the individual’s subjective assessment of comfort and fit needs to be considered. It is not only the way in which the stretch conforms to grip the body (hugging power), but how the garment feels, the first impression when donned and impressions once the garment has been worn and subjected to a range of movements that contribute to the quality of the fit analysis. Movement can be enhanced or inhibited by the garment fit particularly problematic are the shoulder and hip areas. Joints can be classified by the extent of their range of movement. The shoulder is a multi-axial joint that has the highest degree of mobility. The following body area commentaries highlight a way in which a rigid pattern can be developed to assist the shoulder to move freely.

4.2.1 The Bodice
The crucial areas for fit in the bodice are the shoulder angle, the breast and the armseye (armhole). The conventional bodice pattern (Fig. 6) shows the relationship between the garment pattern and the torso. The proximal fit describes body-contouring garments constructed in a stretch knit fabric. The increasing negative proximal fit is related to the garment pattern reduction ratio, influenced by the force exerted on the body, through the modulus or compressive retracting power of the stretch fabric. The proximal fit attributes are as follows:

- **Form Fit (P0)** describes garments that have few wrinkles and no stretch other than tare stretch (a minimal amount) in specific areas of protrusion, to allow the fabric to smoothly contour the body. The stretch fabric exerts no pressure on the body and the stretch does not impede mobility. An example would be close fitting underwear with no holding power.
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- **Power Fit (P6)** refers either to the garment as a whole or to specific areas where the force exerted by the stretch holds and compresses the flesh, changing the body form shape. Applications cover a wide range of sportswear, form persuasive bodywear and medical applications.

4.2.2 The Shoulder Angle
The shoulder angle is determined by posture and elevation of the shoulders and has a significant influence on the fit and comfort of a garment. Rohr explains how to achieve an accurate shoulder angle by taking three simple measurements. These co-ordinates combined in the pattern draft give an accurate shoulder angle for the subject’s body posture when applied to both front and back bodice constructions.

4.2.3 The Set-in Sleeve
For a conventional set in sleeve, the head height and shape of the sleeve reflects the shape of an arm hanging in a relaxed position by the side of the body (Fig. 7). The sleeve torso angle relationship affects the degree of freedom of arm movement. The sleeve fit is at its best when the arm is fully adducted and the
crown conforms smoothly around the top of the arm.

When a set in sleeve is constructed in stretch fabric, movement is restricted as it is impossible to lift up the arm without the fabric straining. A prime example, which illustrates the point, is the cling fit stretch T-shirt with this conventional sleeve construction. When the arm is raised, the fabric adjusts to the new body position. If the underarm seam is lower than the natural armscye line, the underarm sleeve junction will automatically reposition at the anchor or grip point under the arm. Subsequently when the arm is lowered a fold of fabric (producing the effect of an unwanted shoulder pad) appears at the apex of the sleeve crown. A fold of fabric also appears across the chest above the breasts. The T-shirt comfort/fit factor is only maintained by constant rearrangement after movement. This can lead to a negative body cathexis but it is the pattern profile that is at fault and not the inadequacy of the wearer’s bodyshape. Inappropriate pattern geometry in combination with the fabric stretch does not allow the crown to resume its original position when the arm is lowered.

### 4.2.4 The Shirt

Conventional shirt-sleeve pattern construction allows the arms to be raised and move freely. However, it can be observed in Fig. 8 that when the arm is lowered, diagonal wrinkles form towards the under arm. In the illustration Fig. 9 the shirt-sleeve profile (solid line) is achieved by slashing and
spreading the set-in sleeve pattern (dotted line). As the width of the sleeve increases, the underarm is lengthened and the crown becomes shallower, allowing the wearer to move with ease.

In a stretch pattern, if the crown pattern geometry retains a similar profile to the conventional set-in sleeve pattern, with little change in the crown depth, this impairs the quality of the garment fit. When a crown pattern profile similar to a shirt is drafted in a stretch pattern, the width of the lower sleeve may remain narrow with increased width between the underarm seam junctions. This allows the arm to move freely without fabric displacement after movement.

4.3 Proximal Fit Pattern Design

The shape of the garment pieces affects the stretch characteristics. A visual understanding of the overall stretch curvilinear fabric distortion characteristics is essential to the process of pattern production through garment fit analysis and evaluation. Evaluation of the stretch deformation of various shapes, printed with a grid pattern and stretched, such as rectangles, trapezoids and triangles can contribute to maximising the stretch garment fit potential in the pattern design. The area comprising the shoulder angle, armscye, sleeve crown and the protrusion of the breasts demonstrates where directional change and protrusion need an integrational approach in balancing the pattern profile with the deformable fabric geometry for the range of movement required. The transposition of the sample shape deformation of a triangle or trapezoid is informative when applied to the garment pattern for the sleeve crown.

4.3.1 The Dynamic Crown Angle

The alignment of the arm to the body determines the basic shape of the sleeve pattern and the armscye intersection of the bodice pattern. By manipulating the pattern geometry a range of movement to be performed by the arm can be accommodated.

The term dynamic crown angle relates to the depth of the crown, which is calculated from the shoulder point at the top of the crown to the intersection between the arm and chest. This depth becomes shallower as the geometry of the pattern profile changes to utilise the fabric stretch characteristics to enhance the fit quality and accommodate a range of movements. Figure 10 illustrates the bodice to sleeve angle relationship and the shallow crown shape in the bodysuit analysis garment, which approximates a subject standing with the arms adducted at 45°.

4.3.2 Proximal Form Fit

In traditional pattern drafting procedures cardinal (primary) points are positioned using direct circumferential and linear measurements with secondary points derived from basic geometry, all interlinked with straight lines and curves to form a conventional profile. The proximal Form Fit becomes the definitive parametric scalable block pattern profile for both distal and proximal fit. CAD vector procedures are used to place primary, secondary and tertiary nodes which have been derived using a personally extended traditional measurement set, and curve control algorithms to replicate the size and shape of the subject body.
4.3.3 Proximal Action Fit

To produce the action fit, the Form Fit block pattern is enhanced to take into account more parameters, such as fabric stretch characteristics, the desired fit level and the radius of curvature, which can vary for adults and children or for different body zones. The resulting parametric pattern produces an action fit stretch bodysuit that is a true custom fit for the selected body shape size, fit level and chosen fabric. This is illustrated in Fig. 11 by the prototype pattern profiles for the differing body shapes and proportions.

4.4 Proximal Fit Analysis

It is difficult to visualize and quantify the garment-to-body stretch fabric tensional parameters when altering a garment, constructed in a solid colour, using a manual fitting process on a static body or dress stand. Therefore, to objectively evaluate the proximal stretch fit a 2.5 cm grid system has been printed on the analysis body suit which will deform to follow the contours of the body. Taking into account the course and wale pattern reduction one would ideally expect to observe rectangles of a predictable size and a given orientation. However, because of the contoured nature of the body form, areas of tare stretch (a minimal amount of acceptable stretch) are to be predicted in the area of the bust, shoulder blades and buttocks. The analysis is primarily concerned with observation of unacceptable excessive stretch and/or wrinkling by visualising, either physically or digitally in CAD, the deformation of the garment-to-body grid pattern into rhomboids, trapezoids or rectangles.

Compressive stretch fit is not straightforward encompassing a complex set of variables including the user’s subjective preferences. To establish a method for analysing and evaluating the stretch garment fit, the intrinsic and variable problem areas need to be identified and then prioritised into a fitting scheme. A working chart can then be developed to aid the analysis and evaluation process.

4.4.1 Intrinsic Problems

The intrinsic problems are identified as follows:

- Are the seam placements and body landmarks aligned?
- Has a poor cutting technique been used?
- Has there been miss-alignment in the sewing process?
- Are the body measurements accurate?
- Are the draft rules for the body form correct?
- Is the pattern profile correct?
- Does the fabric behave as predicted in terms of stretch?
- Have the effects of the radius of curvature on fabric pressure variations been accommodated?

4.4.2 Variable Problems

The variable problems can be sub-divided into two categories, namely bodice and sleeve bodice junction, as shown below:

Bodice (front then back)
- Is the neckline inside or extended away from the natural boundary line?
• Is the shoulder angle aligned with the apex of the shoulder?
• Has adequate provision been made for the bust prominence?
• Has adequate provision been made for the shoulder blades?
• Is the underarm to waist relationship appropriate?

Sleeve Bodice Junction (front and back)
• Is the shoulder angle sleeve relationship at the armscye boundary appropriate?
• Is the bodice aligned and balanced?
• Is the sleeve angle alignment with body appropriate?
• Are the crown depth and the shaping appropriate?
• Is the sleeve alignment with body balanced?
• Does the armhole shape follow the natural arm boundary?

When donning the garment the seams and landmarks are manipulated into position. The general appearance is then observed, including the girth placement and seam alignment, and the horizontal and vertical balance (front and back). Areas, where the fabric does not follow the intended seamlines and body landmarks are noted. The focus is then on more specific areas, starting with the upper torso at the shoulder, which is observed by sweeping the eyes vertically and horizontally from top to bottom, and around the body viewing the front and back systematically.

Body heat affects the fabric fibres, causing them to relax and mould to the body. The final fit can only be analysed after the fabric reaches equilibrium before proceeding with a pre determined set of movements designed to encompass the full range of movement envisaged (Fig. 12). The grid pattern deforms into different geometric shapes, indicating garment-to-body alignment and the amount and direction of fabric stretch. Gridlines not only enable the observer to identify areas of unacceptable stretch, which is indicative of the pattern profile being incorrect, but also they confirm that the horizontal and vertical toile/body placement aligns as the designer intended. This will also highlight any garment-to-body displacement when the body finally comes to rest after movement.

5 Reflection
Stretch garment assessment is interpretive; the quality of the body contouring fit is inextricably linked with the stretch potential of fabric characteristics. Understanding the stretch behaviour, visually and mechanically, is an essential part of predicting the pattern profile geometry and the optimum orientation of the pattern placement on the fabric to improve the fit-quality and to enhance comfort and freedom of movement. The resultant garment should display no wrinkles, have minimal stretch distortion and facilitate a range of movements without displacing or straining the fabric on cessation of movement. The Form Fit parametric scalable, vectored pattern enables garments to be constructed to fit either a range of different bodyshapes (mass market) or specific individuals (couture) without manual intervention to obtain the appropriate fit.

Defining the fit-quality expectations and the fit level category is paramount in the assessment of the garment-to-body contouring fit relationship. Printing a 2.5 cm grid on the analysis bodysuit toile visualises the stretch fabric characteristics, enabling the assessment of the interrelated factors of seam alignment placement, body landmark positioning and the amount and direction of fabric stretch in garment-to-body fit.

The development of QA/QC tests has contributed considerably in evolving a common language between fibre and fabric producers and garment manufacturers. The development of an industry standard to quantify the degree of stretch extension for stretch pattern

Fig. 12—Fit of the body suit over a range of movements
technology would also be beneficial. It is imperative that the designer/technologist uses a mathematical method for quantifying the degree of fabric stretch to be applied in the pattern reduction process. Overlaying subjective expertise with an objective digital methodology, will improve communication between industry, science, technology and practitioners to further develop compressive stretch garment design.

References
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