Stretching performance

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Abstract

The use of stretch fabrics, which apply varying degrees of compressive stretch, is becoming more significant as the benefits of comfort, mobility and shape retention, are increasingly desired for sportswear, cosmetic body shaping and medical applications. There are numerous software packages that, at first glance, appear to offer the potential to produce good fitting garments. The body is scanned, taking the necessary measurements to produce virtual mannequins where prototype designs are adjusted on screen, before producing real garments. An area that major software vendors and research establishments alike have been pursuing is the reverse engineering (pattern flattening) process from the virtual 3D parametric mannequin that has been wrapped with the desired garment design, into the 2D domain of the pattern pieces. At this point in time nobody appears to have overcome the reverse engineering challenge because of the number of variables that the evolving algorithms have to accommodate. My passion is in the area of developing good fitting compressive stretch garments that enhance self-esteem, which is the focus of this paper. The Form Fit pattern, developed by the author, was not constructed by modifying the closest 'standard' pattern but from an extended body measurement set that captures body shape and proportions. As an aid to the objective evaluation of stretch fit garments a 25mm grid system has been printed on an analysis body suit. The 3D garment fit was evaluated then reverse engineered, using nip and tuck algorithms, accumulated over years of experience. The stretch garment-to-body pattern design fit was optimised through an iteration process. Adopting a parametric approach to pattern profiling enabled other variable to be considered; fabric stretch and recovery, radius of curvature and pressure implications. A true test of custom fit should be a direct correlation

Keywords:
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3D pattern design,
reverse engineering

between the 3D body, the pattern geometry and the fabric parameters. The starting point for developing stretch garment technology is building on craft skills to comprehend and articulate the technical processes. This will impel new paradigms of theory and practice that will enable designer/technicians to link more effectively with emerging technology to offer garments that enhance human potential.

Introduction

Since the introduction of Lycra in the mid 20th Century the inherant benefits to comfort and mobility have been utilised increasingly in all clothing applications' particularly garments which closely contour the body. Initially it was developed as a replacement for rubber in corsetry. However, the understanding of how to optimise the stretch potential in pattern design for performancewear is, in relative terms, still in its infancy. It is this area which is the focus of my research. Comprehensive literature detailing all aspects of stretch pattern development has not been available, so over the years, through a heuristic approach, I have intuitively overcome numerous fitting problems in stretch garment pattern design. Tacit or embedded knowledge underpins my whole approach to designing. I believed that a good fitting basic block pattern that replicates the body contour shape and an understanding the behaviour of stretch characteristics is an essential starting point for garment design, whatever the application.

The Lycra revolution

During the 1950s substantial improvements in processing white rubber meant that the filaments were more resistant to discoloration and to existing forms of degradation. This, combined with the introduction of high-speed two-way stretch warp knitting machines, fed the increasing demand for stretch support garments. A good example is the 'roll-on' constructed from a complete circle of elastic fabric, which one literally rolled on over the hips. However rubber still had inherent problems, not only was it heavy and hot to wear but also it was prone to drying out resulting in a loss of elasticity and a short flex life. With the unsatisfactory nature of rubber and the growing demand for lightweight form persuasive garments, a synthetic alternative to needed to be found.

In 1937, Bayer, Rink and co-workers at the German Company Bayer Ag discovered a polyurethane-based process for producing filaments with elastic characteristics (Meyer et al 1995, pp.58, Koch 1995, pp.30-40). A new classification had to be found for this fibre and it was designated an elastane or elastomeric fibre.

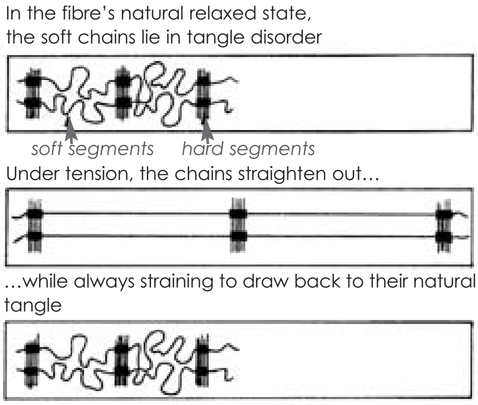


Figure 1. Elastane Stretch and Recovery
Source: Du Pont Technical Information (1996:5)

The molecular structure endows the fibre with its built-in capacity for stretch and recovery (Figure 1). This orientated block co-polymer structure consists of long, disordered, flexible molecular chains (soft segments), which are responsible for the rubber-like high stretchability of the elastane yarns and tie points (hard segments), which are crystalline regions formed from short chains and are responsible for the network of cross links During deformation the stress is transferred to the molecular chains, forming soft segments which uncoil and extend with the hard segment matrix, causing the yarn to spring back to its original length when the stress is released after deformation (Koch 1995, p 32). It is stronger and more durable than rubber and has two or three times more restraining power, at one third of the weight. It can be extended up to seven times its own length and recover immediately, almost to its original length, when the tension is relaxed.

Following ten years of intensive research DuPont de Nemours and Co, elastomeric fibres based on polyetherurethane were introduced to manufacturers. Finally in October 1959 it was launched commercially using the trade name 'Lycra' in Britain. In America and Canada the fibre is referred to as spandex, the generic term for elastane or elastomeric fibres, which was created by transposing the syllables in the word expand (Gohl and Vilensky 1983 pp.99-104). After a further three years of intensive research and evaluation Lycra (elastane) was brought into full-scale production in 1962. Continuing innovation has expanded the capabilities of Lycra. Ongoing innovation in developing Lycra is continuing at Invista.

The development of this truly innovative fibre however did not precipitate an equally innovative approach to stretch garment pattern technology. One has to question consensus in current texts (Haggar 2004, Armstrong 1995, Aldrich 1996, 1997) of using adapted conventional pattern construction co-ordinates that are reduced by arbitrary stretch factors as an appropriate starting point for developing body contouring stretch garments. Stretch pattern research does not encompass the whole body. Also the impact of the fabric stretch distortion characteristics on the pattern profile geometry is not addressed (Bonnigheim 1996. Chun, J and Hue, J H 1998. Fan, J, et al 2004. Ibrahim, S.M 1968. Kirstein, T, et al 1999. Krzywinski, S. et al 2001. Ziegert, B and Keil, G 1988). Pattern design for stretch fabric, using the simplified shapes of modified conventional patterns, will not automatically give an acceptable whole body contour fit.

Virtual technology

Computer animation has accelerated the development of parametric mannequins and simulated fabric drape software, which is ongoing. In the sales and marketing arena, to create a desire, bodies are scanned and then clothed in the virtual realm. The offering of virtual fit to the customers' own body measurements, scanned in a booth, in a matter of moments, suggests the fit we desire is available. All that is required then is to; access the virtual fitting room, (Browzwear, Dressingsim, Fitme, Miralab, Optitex) input your preference, choose an outfit, view the virtual try on from different angles and moving around. Then, if you like what you 'see', buy the real thing. The manufacturers' virtual fit model is expected to increase comfort and provide a good fit quality in the final product. The discerning buyer will even be able to assess the tactile quality of fabric on the virtual mannequin. Magnenat-Thalmann is heading a project Haptex (2007) to develop a prototype haptic glove, which makes virtual fabric feel just like the real thing. The prospect of not having to spend time endlessly trying on garments in a cramped fitting room is very seductive. Although this may be sold as a wonderful buying experience, isn't the whole point of trying on clothes to engage with the garment; the tactile quality of the materials, the colour, the style, the quality of the fit and the overall comfort factor that boosts self-esteem. Having emotionally engaged with the garment it can be almost forgotten, as comfort does not consciously register like the feelings of discomfort. Comfort is subjective dependant on personal preference, both physiological and psychological, encompassing all the senses. How can this be addressed in the virtual realm and is it appropriate?

Because CAD software manufacturers have over the years expanded their product offering by integrating a number of design and production solutions, it is common to find that there is little integration compliance between the range of modules they offer.There are numerous software packages that, at first glance, appear to offer the potential to produce good fitting garments. The body is scanned, taking the necessary measurements to produce virtual mannequins where prototype designs are adjusted on screen, before producing physical prototypes, followed by the finalised garment production run. Although body measurement data can accurately capture body shape, the programs that input the data into a parametric pattern for a variety of shapes and sizes, tend to take the nearest traditional pattern and use the new measurements to adjust it with the expectation that it will fit. Krzywinski (2005) suggests the development of a revolutionary design methodology and tools enabling direct garment design in 3D, which will automatically be flattened into 2D patterns, will enable designers with no pattern making capabilities to create and evaluate new garment designs on a virtual model. This is being marketed as ideal.

Over the past decade or so a lot of emphasis has been placed on interactive fashion design developing 2D pattern pieces from virtual 3D images (Volino 2005). Integration of human and technical resources by way of virtual prototyping reduces the cost of the complete new product development cycle from sketch drawing to pattern making. This is exciting and should be good for the industry in reducing the number of physical prototypes and shortening the time to develop a new collection. Currently most software systems offering virtual 3D design and fit cannot change the pattern in real time, although it has been suggested otherwise. It takes expertise in pattern cutting to achieve the virtual 2D to 3D fit. 3D virtual garment design incorporating pattern construction for physical sample production and manufacture is still some way off

(Wang 2005). The bottleneck in the production process which doesn't seem to have been resolved at this point in time, because of the number of variables that the evolving algorithms have to accommodate, is reverse engineering the designed garment pattern in the 3D virtual realm, into the 2D pattern pieces.

The garment industry relies heavily on physical prototyping calling for pattern cutting skills to manually develop the 2D pattern pieces, which may then be passed into the 3D virtual realm for garment visualisation. Mass spring systems are under development to assist in the 2D to 3D process. In principle a 2D pattern that has been generated by a typical garment CAD package is assembled and wrapped around a virtual 3D mannequin. An iterative process based on Newtonian laws' ordinary differential equations (ODE) stabilises the simulation until a state of 'balance' is achieved whereby stresses and strains within the garment are minimised. Analysis between the undistorted 2D pattern pieces and the deformed simulation may be made. Depending upon the acceptable geometric accuracy of the virtual mesh, 'stabilisation' can take from tens of seconds to minutes. Luo (2005) proposes to reduce this stabilisation time by applying energy imbalance algorithms, generated by 2D manipulation, directly to the existing 3D virtual mesh, as opposed to repeating the total stability process. At this point in the development cycle, mass spring systems could be used for basic analysis of close fitting garments but cannot in themselves bring about a better fit. Variables that the process relies on include; a realistic mannequin, well cut 2D pattern pieces, fabric parameters, garment-to-body fit, garment-to-body collision.

My area of research is in producing efficient 2D pattern profiles that can be passed onto the 3D virtual environment, which is based on body geometry, fabric parameters, nip & tuck algorithms, decades of experience and a passion for the subject.

Pattern design to enhance movement

In garments with conventional pattern co-ordinates, the looser the fit means a greater number of body shape anomalies can be accommodated. Conversely the tighter a garment is, the greater the garment to body fit disparity. Without visualising the curvilinear distortion of the stretch fabric as it contours the body this is not always apparent, as some inconsistencies can be absorbed within the stretch fabric parameters.

Fit definition

The term 'garment fit' can either refer to the design/style or the proximity of the garment to the body. For conventional garments the fit can be loosely interpreted but for stretch garments fit is paramount in terms of relating the garment to body contour pattern co-ordinates and fabric stretch parameters to determine fabric tension and predict garment pressure. Therefore for clarity in describing the proximity of the garment to the body I have introduced 2 anatomical terms, *distal* and *proximal* fit.

Distal is away from the centre of the body and proximal is towards the centre of the body. On a *distal proximal fit continuum* the body contour becomes the zero proximal reference point (Watkins 2005, 2006)

Garments along the distal continuum away from the proximal fit describe garments that are constructed from fabrics that are either non-stretch or have minimal stretch to enhance comfort. These garments are essentially an external structure ranging from a *Loose Fit* through *Semi-fitted* to *Fitted*. The proximal fit describes body-contouring garments constructed in a stretch knit fabric. The increasing positive 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 zero proximal reference point or *Form Fit* describes garments that have few wrinkles and no stretch other than tare stretch (a minimal amount) in specific areas, 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. The Form Fit body suit block pattern draft co-ordinates are the key in replicating the body shape that underpins the different fit levels. *Cling Fit* includes fashion garments where the stretch fabric clings to the body curves does not significantly compress or alter the body contour. *Action Fit* describes most stretch sportswear and exercise garments where the retracting stretch effectively grips the body contour. *Power Fit* 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.

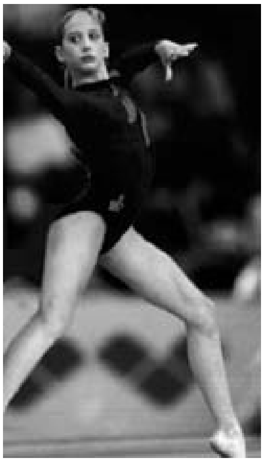
It is the arbitrary garment-to-body fit relationship within the conventional pattern profile geometry that ultimately undermines the fit potential of fit stretch garments. The pattern profile becomes increasingly distorted as the fabric is incrementally stretched around the body contours. Anchor or grip points, which restrain the fabric, affect the stretch fit and any movement impacts on this.

Dynamic posture

In developing stretch performance garments the ability to balance interrelated factors in a design specification is paramount. Dynamic posture is one key factor. Posture describes the physical alignment in which the body frame head and limbs are carried. In relation to pattern design for fashion, posture is generally used to describe the static upright position of the body. However for sportswear posture is used to describe the movements that need to be incorporated in the pattern design. Garments are designed to enhance individual performance, comfort and freedom; they can help give an athlete that competitive edge.

A: the equestrian seated astride the horse.
Source: World Sports Activewear (1998)

B: the cyclist curved over in a riding posture.
Source: World Sports Activewear (1998)



C: the gymnast with strong body lines.
Source: The Gymnast (1996)

Figure 2. Illustrates examples of garments to enhance performance

Traditional pattern design

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 pattern design. However in a conventional stretch bodysuit poor fit is not always apparent visually until the garment has been worn and washed several times. The fabric may then begin to degrade at the underarm and body rise or the seam stitching bursts. Watkins (2000) outlines an objective approach to visually evaluating stretch fit.

The body area commentaries following highlight some of the ways in which rigid patterns are developed to promote movement.

The trouser

This illustration (Figure 3) shows the relationship to the body of a conventional trouser pattern. Pattern drafting systems in general apportion the fork point extension beyond the hip by a derived mathematical formula to define the bodyrise shape. The garment fit is determined by the seat angle, bodyrise and the overall fork length plus a closed or open leg position.

Riding breeches

In the draft for non-stretch riding breeches illustrated (Figure 4). The seat angle at the back is increased and the front body rise is shortened to reduce fabric buckling, when seated. The increased width across the seat at the fork point accommodates the seated buttock expansion. The legs are abducted to allow for open leg posture and the gore at the back of the knee replaces the folds produced by the bent knee.

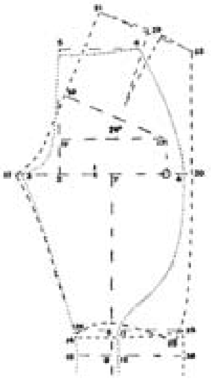


Figure 3. Conventional Trouser Block Pattern. Source: Armstrong (1987:531)

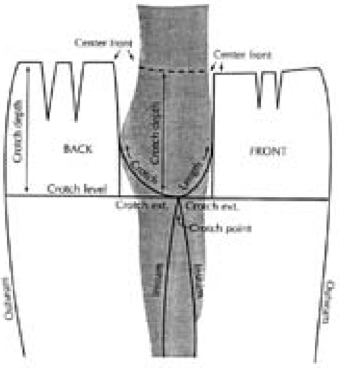


Figure 4. Conventional Pattern Riding Britches. Source: Hulme (1946:129)

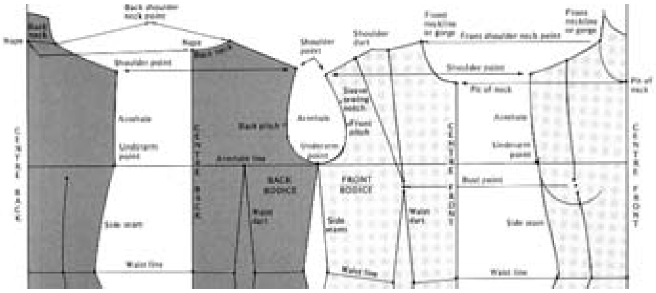


Figure 5. Conventional Block Pattern Relationship to Body Measurements. Source: Shoben and Ward (1980, p. 39)

The bodice

The crucial areas for fit in the bodice are the shoulder angle, the bust and the armhole. The conventional bodice pattern is illustrated in Figure 5. Shoben and Ward (1980) outline the relationship between the garment pattern and the torso.

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. Hutchinson (1977) outlines a method for determining the shoulder seam placement using a frame to measure the shoulder angle, however, the technique uses complex equipment that is not readily available. Rohr (1957, p. 7) explains how to achieve an accurate shoulder angle by taking three simple measurements. Firstly measure the shoulder height, by taking the tape from the waist to the shoulder at the neck, keeping the tape parallel to the centre line. Then take the front body width by measuring from shoulder point to shoulder point and dividing the length in half. Lastly measure the shoulder angle by taking the tape from the centre waist to the shoulder at the armhole. These co-ordinates combined in the pattern draft give an accurate shoulder angle for the subjects body posture when applied to both front and back bodice constructions.

The sleeve

Altering the sleeve pattern profile accommodates a range of movement to be performed by the arm. The alignment of the arm to the body determines the shape at the armscye to bodice intersections.

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 (Figure 6). The sleeve torso angle relationship affects the degree of freedom of arm movement. The pattern adjustment that lowers the armhole, maintaining the crown height and shape in the sleeve, reduces the under arm seam, this ties the arm closely to the body. The sleeve fit is at its best when the arm is fully adducted and the crown conforms smoothly around the top of the arm.

For a conventional set in sleeve, the head or crown conforms smoothly around the top of the arm. The shape of the sleeve reflects the shape of an arm hanging in a relaxed position by the side of the body. The converging bodice and sleeve seams, illustrated in figure 7, influence mobility of the arm.

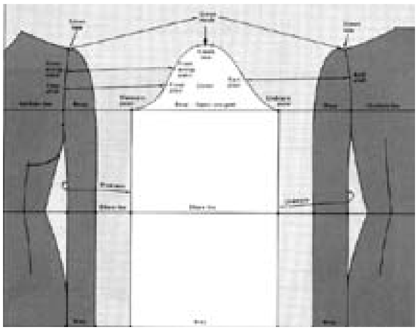


Figure 6. Set in Sleeve Pattern
Source: Shoben and Ward (1980, p. 40)

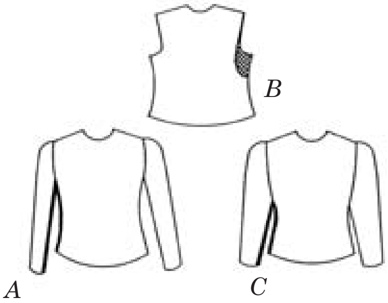


Figure 7. Underarm Line
Source: Watkins (1995, p. 253)

A: maintains the crown height and conforms to the body under the arm and down the length of the underarm seam, this does not necessarily provide for the arm to abduct more fully.

B: shows the pattern adjustment lowering the armhole and C: demonstrates the resulting shorter bodice and underarm sleeve length, which ties the arm closely to the body restricting movement.

The construction of the crown, in combination with the convergence of the four seams under the arm, can restrict abduction of the arm. This is due to insufficient fabric across the crown and towards the underarm seam junction. The arm can only be abducted approximately half way between waist and shoulder without pulling the rest of the garment out of alignment. As a consequence of the fabric straining when the arm is raised, wrinkles form across the top of the arm through to the underarm restricting movement.

Conventionally the set-in sleeve block pattern constructed in non-stretch fabric accommodates the arm when hanging loosely by the side of the body as illustrated previously in figure 5.

When constructed in a stretch fabric movement is restricted, as it is impossible to lift up the arm without the fabric straining. The cling fit stretch T-shirt is a prime example. When the arm is raised, the fabric adjusts to the new body position and the underarm seam, if it 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 (LaBat and DeLong 1990) but it is the pattern profile that is at fault and not the inadequacy of the wearers' 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.

The shirt

Conventional shirt-sleeve pattern construction allows the arms to be raised and move freely. However, it can be observed in figure 8 that

Figure 8. Shirtsleeve
Source: Ladbury (1984, p. 107)

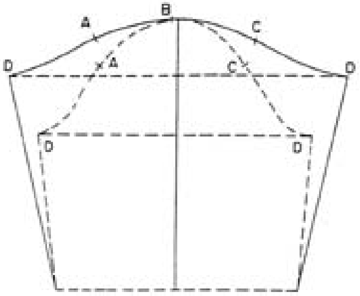


Figure 9. Pattern Manipulation
Source: Pivnick (1958 p. 58)

when the arm is lowered, diagonal wrinkles form towards the under arm. In figure 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.

Proximal fit pattern design

The shape of the fabric 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 of the shoulder angle, armscye, sleeve crown and the protrusion of the breast illustrates where directional change and protrusion need an integrational approach 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 sleeve crown.

For the proximal fit pattern profile I have introduced *The Dynamic Crown Angle* that 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. Figures 10 and 11 illustrate the bodice to sleeve angle relationship and the shallow crown shape in the analysis garment, which approximates a subject standing with the arms abducted at 45°.

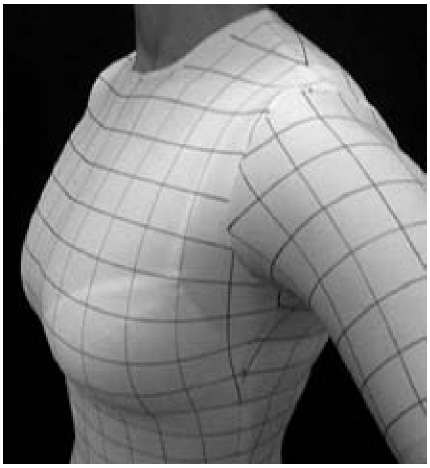


Figure 10. Visual Analysis Front View

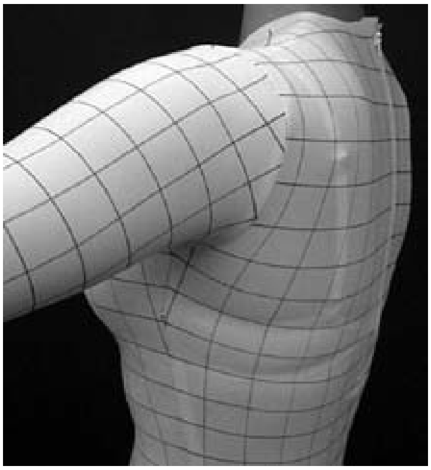


Figure 11. Visual Analysis Back View

Proximal form fit

The geometry of the stretch block pattern profile can only be developed successfully through understanding the complex relationship between the dynamic form, the stretch fabric behaviour and the two dimensional pattern profiles. My approach to pattern design has been analysing traditional procedures in pattern design and garment fit to accommodate different bodyshapes, posture and movements. The 3D garment fit is evaluated then reverse engineered, using nip and tuck algorithms, accumulated over years of experience, and then re-applied to the evolving 2D pattern pieces. Replicating the size and shape of a person in the pattern profile is the key. Good fit is dependent on the pattern drafting co-ordinates co-operating with the stretch characteristics conforming to the shape of a person. My research has enabled me to develop a *Form Fit* block pattern using a personally extended set of traditional measurements. The new *Form Fit* block pattern is the basis for developing both distal and proximal garment fit. Producing a form fit flat pattern, without darts that closely adheres to the contours of the body without restricting movement, is complex. In woven fabric, darts and ease are used to manipulate the fabric around the form and allow movement. In a knit-stretch garment without darts to contour the body, a degree of stretch distortion in areas of protrusion is inevitable.

An optimised contour fit pattern should produce a garment that has no wrinkles, minimal stretch distortion and conforms to the body, rather like a second skin.

Proximal action fit

To produce the Action Fit the algorithms for the Form Fit patterns are enhanced to take into account the selected 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.

Objective fit analysis

There are numerous texts on the fit of non-stretch garments Liechty et al (1986) is invaluable as a multi method approach is outlined. However in stretch garments it is more complex to visualise and alter the garment fit manually. The quality of the fit becomes dependant on the subjective expertise of the fitter. Therefore to objectively evaluate the fit a 25mm grid system has been printed on the analysis body suit. The stretch garment-to-body pattern design fit is optimised through an iteration process. A grid system allows the designer to visualise stretch deformation over the body contours. 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.

Movement fit analysis

The fit relationship is complex and a more representative evaluation is conducted on a subject rather than a dress stand. The assessment takes place after the garment has warmed up and a series of movements, which fully articulate the body and the fabric, have been performed. Body heat affects the fibres in fabric causing them to relax and mould to the body. On cessation of movement the fabric adjusts to reach equilibrium in contouring the body. As can be observed in figure 12 the fit is not displaced during movement.

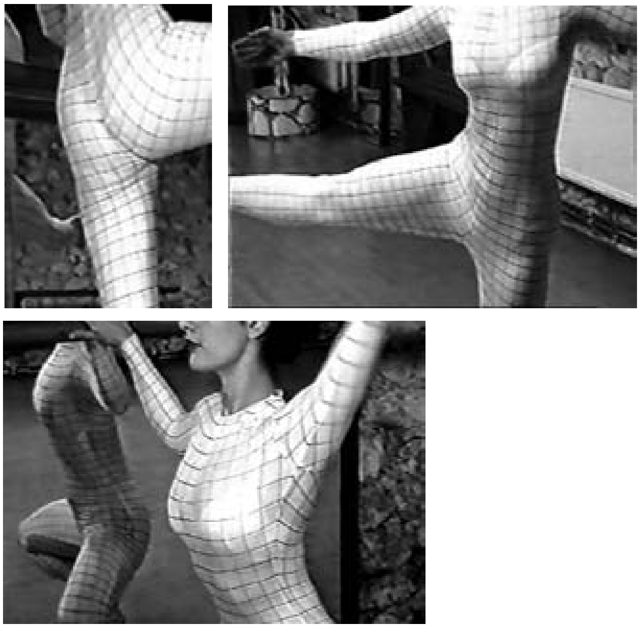


Figure 12. Action Fit: Movement Analysis

Summary

Over the last ten years there has been an increase in demand for stretch garments, which contour the body for a variety of application. It was the development of Lycra in the 1950s that led the way.

Developing patterns for stretch fabrics is not straightforward. Technical literature to date does not detail objectively how to optimise the stretch potential in pattern design for performancewear. If the stretch fabric extension rates are arbitrary and the pattern rationale does not meet the dynamics of the individuals fit requirement, it is difficult to objectively assess and predict garment fit. There is little information on where and by how much to reduce the block pattern profile geometry in order to fit comfortably without fabric displacement when the body comes to rest after movement. A thorough understanding of the dynamics of developing stretch pattern technology can only enhance the designers' capacity to interact effectively with technology.

My passion is garment fit to enhance self-esteem. My research is in producing efficient 2D pattern profiles that can be passed onto the 3D virtual environment based on body geometry and fabric stretch parameters. This is an objective approach to garment design for stretching performance, whatever the application.

References

Aldrich, W. (1996), *Fabric, Form and Flat Pattern Cutting* (Oxford: Blackwell Science)

Aldrich, W. (1997, 3rd ed.), *Metric Pattern Cutting* (Oxford: Blackwell Science)

Armstrong, H. (1995, 2nd ed.), *Patternmaking for Fashion Design* (USA: Harper Collins)

Bray, N. (1978, 2nd ed.), *Dress Fitting* (Oxford: Blackwell Science)

Chun, J. & Hue, J.H. (1998), Development of Bodice Patterns Modifications System Based on the Stretch Rate of Knit. *ITAA Proceedings* USA, pp. 110-111.

Gohl, E.P.G. & Vilensky, L.D. (1983, 2nd ed.), *Textile Science, An Explanation of Fibre Properties* (Melbourne: Longman)

Haggar, A. (2004, 2nd ed.), *Pattern Cutting for Lingerie, Beachwear and Leisurewear* (Oxford: BSP Professional Books)

Haptex (2007), http://haptex.miralab.unige.ch/

Hulme, W.H. (1946), *The Practice of Garment-Pattern Making* (London: National Trade Press Ltd)

Ibrahim, S.M. (1968), 'Mechanics of Form-Persuasive Garments Based on Spandex Fibers', *Textile Research Journal* September, pp. 950-963

Koch, P.A. (1995), 'Elastane Fibers (Spandex)', *Man-Made Fiber Year Book (CFI)* **2**, pp. 30-40.

Kirstein, T. et al, (1999), 'Pattern Construction for Close-Fitting Garments made of Knitted Fabrics', *Melliand Textilberichte* **80** (3), March, pp. E46-48/146-148

Krzywinski, S. et al (2001), 'Links Between Design, Pattern Development and Fabric Behaviour for Clothing and Technical Textiles', *JTATM* **1** (4) (NC State University)

Krzywinski, S. and Rodel, H. (2005), 'Virtual Product Development for Close-Fitting Garments of Knitwear with Elastan Yarns', *2nd*

International Conference of Textile Research Division NCR Cairo, Egypt. April 11-13

LaBat, K.L. & DeLong, M.R. (1990), Body Cathexis and Satisfaction with Fit of Apparel, *Clothing and Textiles Research Journal* **8** (2), Winter, pp. 43-48

Ladbury, A. (1984), *Dressmaking with Liberty* (London: Guild Publishing)

Liechty, E.G. et al (1986), *Fitting & Pattern Alteration: A Multi-Method Approach* (USA, Fairchild Publications)

Luo, Z.G. & Yuen, M.M.F. (2005), Reactive 2D/3D Garment Pattern Design Modification. *Computer-Aided Design* **37** (1), pp. 623-630

McConville, J.T. (1986), 'Anthropometric Fit Testing and Evaluation in Performance of Protective Clothing ASTM STP900', *Performance of Protective Clothing ASTM STP900*, pp. 556-568

Meyer, R.V. et al (1995), 'Elastic Fibres – Chemistry, Properties, Applications', *World Sports Activewear* **1** (1), July, pp. 58-60

Pivnick, E.K. (1958, 3rd ed.), *Fundamentals of Patternmaking for Women's Apparel Part 2* (New York: Pattern Publications)

Rohr, M. (1957), *Pattern Drafting and Grading* 2nd Ed Eastchester, (New York: M. Rohr)

Shoben, M. & Ward, J. (1980), *Pattern Cutting and Making Up: The Professional Approach 1 Basic Techniques and Sample Development* (London: Batsford Academic and Educational Ltd)

The Gymnast (1996), British Gymnastics Official Magazine, Cabbell Publishing Ltd

Volino, P. et al (2005), 'From Early Virtual Garment Simulation to Interactive Fashion Design', *Computer-Aided Design*, **37** (1), pp. 593-608

Watkins, P.A. (2000), Analysis of Stretch Garments. Textile Institute 80th World Conference, Manchester, April

Watkins, P.A. (2005), Custom Fit Pressure Garment Pattern Profiling. Wearable Futures: Hybrid Culture in the Design and Development of Soft Technology conference. University of Wales September

Watkins, S.M. (1984, 2nd ed.), *Clothing. The Portable Environment* (USA: Iowa State University Press)

Wang, C.C.L. et al (2005), 'Design Automation for Customized Apparel Products', *Computer-Aided Design* **37** (1), pp. 675-691

World Sports Activewear (1998, 'Cyclist on Bicycle', *World Sports Activewear* **4** (1), Spring, p. 1

Ziegert, B & Keil, G. (1988), 'Stretch Fabric Interaction with Action Wearables: Defining a Body Contouring Pattern System', *Clothing and Textiles Research Journal*, **6** pt.4, Summer, pp 54-64

http://www.browzwear.com/

http://www.dressingsim.com/

http://www.fitme.com/

http://www.invista.com/ http://www.optitex.com/

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