From calculators to 21st century computing: successes and opportunities in digital technology for textiles

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The paper reviews the applications of digital technology to the textile industries from the mid-20th century to the 21st century. The advances in the available tools are first described. Sections then cover aesthetic design, machines and operations, and commercial and retail, all of which are in general use. For engineering design and the "virtual catwalk", there are great opportunities but software from academic research has hardly been taken up by industry.

Key words: *computing, textile design, machine control, structural mechanics, visualization.*

1. Introduction

The textile industries have seen several periods of rapid change. The earliest inventions were spread over many years and places starting in prehistoric times and had become well established by around AD1000. Power came to the machines between 1775 and 1825. The period from 1950 to 1980 saw major innovations in machines and processes. From the 1970s onwards, we have seen the growing impact of electronic digital technology. The aim of this paper is to give a broad overview of the successful developments and to discuss the challenges that remain. The Appendix, which shows the programme of the First International Conference on Digital Technologies for the Textile Industries, held in Manchester in September 2013, demonstrates the great diversity of interest in the development and application of digital technologies in the textile and clothing industries.

2. Development of the Tools

In the late 1940s and early 1950s, when I started my research career, the tools that we had for the mathematics, data handling and modelling of the structure and properties of fibres and textiles consisted of pencil and paper, logarithmic and other tables, and slide rules. The only mechanical aids were electro-mechanical calculators, Fig.1, which were particularly useful for statistical analysis. But change was coming. In the University of Manchester, F C Williams had built "Baby", Fig.2, which was claimed to be the first programmable computer – a device of vacuum tubes and Post Office relays. This was followed by larger computers, which were used for the most demanding research in the University.

Fig.1 Electro-mechanical calculator

Fig.2 Replica of "Baby", built for its 50th anniversary

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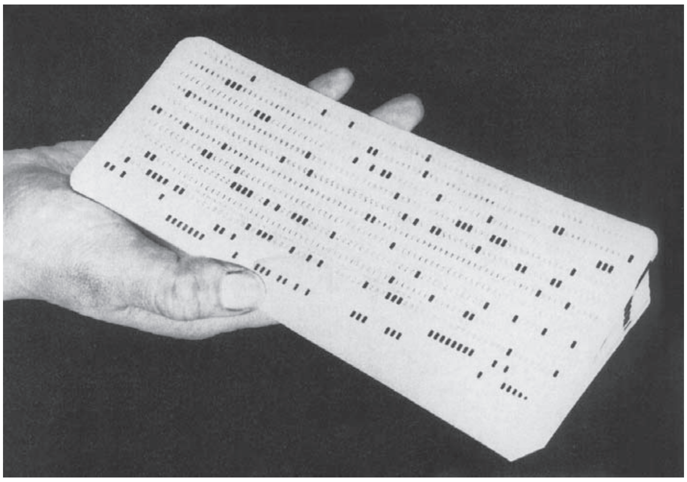


Fig.3 Punched cards

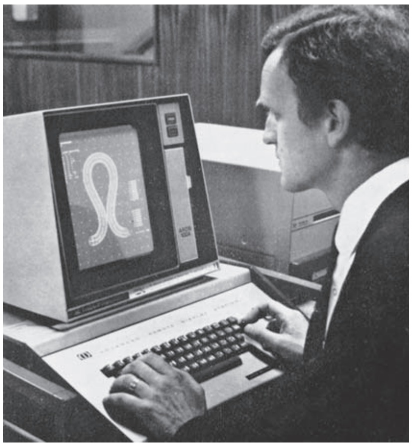


Fig.4 On-lime acces

By the time that I was supervising graduate students in the mid-1950s, the Manchester ATLAS computers were open to all. Programs were written by the students in Atlas Autocode, a good language that eventually died due to competition from IBM's Fortran, and submitted on punched cards, Fig.3, with a response coming back to a card reader hours or days later. Subsequently, there was access by teletype, but still a queue waiting for the response. Although I did attend a Fortran course, I was never proficient at programming. My role was strategic not tactical.

In 1963/64 I spent a year at MIT. Time-share and on-line access was being pioneered. Professor Stanley Backer then used these facilities to develop an on-line literature retrieval system for the US textile industry. In 1966, this was demonstrated in Manchester using the trans-Atlantic commercial Telex network to contact a computer in Cambridge, Massachusetts. However, the situation in Manchester was complicated. Professor Gordon Black, Director of Central Computing, believed only in batch computing. Fortunately, Professor Howard Rosenbrock, Director of the Control Systems Centre, had a different view and installed a PDP10 with a number of terminals for on-line access. Milos Konopasek was able to use this facility, Fig.4, when he came to Manchester as a Research Fellow in 1968. His work, comtinued after he moved to USA, covered a wide range from a network algoriithm for woven fabric structure, which became the basis of the mathematical software program, TK Solver, and bending curves in knit fabrics to an alorithm for lay-planning.

In due course on-line access to central computers became the norm to be followed by micro-computers. In the early 1980s, the Department of Textiles bought a BBC Acorn personal computer. Shortly before I retired in 1985 from UMIST, Dr Susitoglu used it to model the mechanical properties of wool for our paper at the 7th International Wool Textile Research Conference. Now, with the predictions of Moore's Law, the norm is for general purpose PCs or small specialist devices to meet most of the needs for textile design, machine control, and modeling, with main-frame computers handling large data sets.

What of the future? For some of the most exciting new ways of exploiting digital technologies for the textile industries, we should look at the latest advances in supercomputers and cloud computing.

3. Textile Design

With the growth of computer graphics, textiles were a natural application. Initially, designers were antipathetic, preferring what they viewed as the freedom of freehand drawing. In the early1970s, Roger Nicholson, Professor of Textile Design at the Royal College of Art in London, explored the use of computer graphics using facilities in the cartography department of the College. W D Cooke and I then joined him in an application to the Wolfson Foundation to develop a textile CAD system. Referees were favourable, but it is reported that the Secretary of the Foundation met a textile manufacturer at his Club and was told “Why do designers need computers? They have pantographs!”. That killed it.

Nevertheless, companies and academic researchers began to develop systems. One example, particularly suited to tartans and checks, was ScotCad originating from the Scottish College of Textiles in Galashiels. In 1975, at UMIST in Manchester, Peter Grigg, an electrical engineer with computing expertise, was appointed as a Lecturer in Textile Engineering with a remit to develop a textile CAD operation, though designers in the department showed little interest in the activity. Not wanting to be tied to the University's central computer, he acquired two redundant, stand-alone computers from the British Navy. They were about the size of upright pianos with a power that was orders of magnitude less than a modern PC. The effort was successful, UK government grants and support from the Wolfson Foundation led to the formation of TCS

Ltd in the early 1980s. Their first, vital order was from a New Zealand carpet manufacturer. In the 1990s, the company was bought by NedGraphics BV.

Interestingly, the Ned Graphics website states "For more than 30 years NedGraphics has been developing software for the Fashion industry." This confirms the 1980s as the time when textile designers began to embrace CAD. Now it is the almost universal mode of operation and many software companies supply the market. Following parallel developments, fashion designers now use computer graphics for their creations.

Fig.5 J. M. Jacquard

Fig.6 A Jacquard fabric

4. Machines and Operations

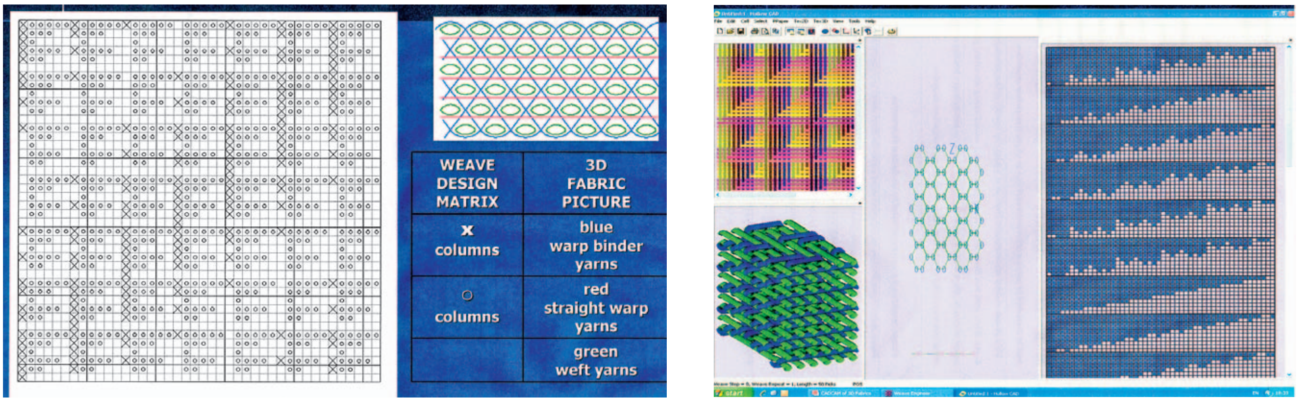
Textiles can claim to be the first digital technology to be applied to machines. In 1725, Basile Bouchon, a silk weaver in Lyon, added a punched roll of paper to a handloom. Until then, between each pick in a draw loom, the weaver or his assistant had to raise or lower groups of cords that held the warp threads in order to generate a simple pattern; the hand-punched paper enabled this to be done automatically. Bouchon's name is not well known and it was 75 years later that Joseph Marie Jacquard, Fig.5, recognized that individual threads could be controlled by a long role of punched cards. "Jacquard weaving" was born and used for complicated patterns, Fig.6, or even small works of art. This purely mechanical, digital process remained the sole way of making fabrics with elaborate patterns for almost 200 years.

Change came in the 1980s. First there was a brief intermediate stage in which card-punching changed from manual to electro-mechanical. Direct control of the weaving machine was not easy. Peter Grigg tried to develop a machine at UMIST in Manchester, but was beaten by the heating of the actuators. It was at ITMA in Milan in 1983 that Bonas Machine Company Ltd launched the first electronic Jacquard. Other companies, notably Staubli, have followed.

The route is now clear from the designer's computer to the computer controlling the weaving machine. The procedure can be used not only for traditional planar weaves, but also for the recent developments of 3D fabrics with interlacing in multiple layers or the formation of complex 3D shapes. The program, Weave Engineer, developed by Xiaogang Chen, provides a simple route to the weave structure, which can then be transferred to the machine control. Fig.7 shows two examples of its application.

Similar developments have occurred in other parts of the textile industries.

- In braiding, there is digital control of the movement of the yarn carriers, in knitting of the stitch pattern, and in embroidery of the needle.
- Digital technology has produced an even more revolutionary change in the production of knitwear. Instead of having to sew separate pieces together, computer-controlled flat-bed knitting machines, pioneered by Shima Seiki and Stoll, enable the whole shape of a garment to be controlled and produced in one piece. Other



WEAVE DESIGN MATRIX	3D FABRIC PICTURE
x columns	blue warp binder yarns
○ columns	red straight warp yarns
	green weft yarns

a) b)

Fig.7 3D weave design: a) six layer angle interlock for composite reinforcement; b) hollow structure that could be used for ballistic protection

Fig.8 Digitally produced lay-plan

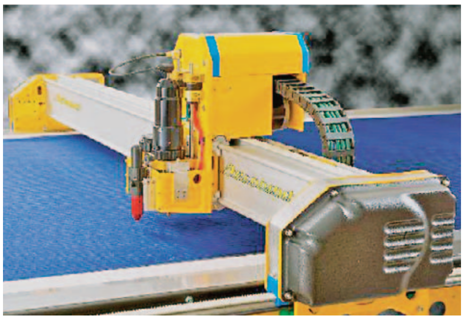


Fig.9 Digitally controlled cutting

shapes can be produced for technical uses.

- Digital printing is standard for text and graphics on paper, but it is more difficult to achieve high quality on fabrics. The development has lagged behind control of weaving but is now being more widely used. This opens up new possibilities for designers. Pattern repetition would not be obligatory unlike roller or screen printing. Variations could be as long as the file allows. Random effects could be introduced. For example, in a pattern of circles, there could be changes in locations within a given range, size and colour – or, in a floral design, random variations could be introduced in the forms of flowers, leaves and stems. Design details could be fitted to match where they should appear on the final product, such as a lady's dress or upholstered furniture. With good programs, a new world would open up for designers – going beyond printing a logo on a T-shirt.

At the start of the textile/clothing chain, a company such as Toyota naturally uses digital technology in design and in production machinery in a similar way to its use in automobile production. The same applies to companies that serve only the textile market, but it is beyond the scope of this paper to go into detail.

At the other end of the chain, the mass production of woven fabric garments posed a challenge to programmers. The garment designer specifies a collection of many pieces of different sizes and shapes that have to be sewn together. The mathematical puzzle is "*What arrangement of the pieces minimises the waste from the gaps between the pieces*?" The possible arrangements are infinite. Fortunately, clever algorithms have been developed that, if not reaching the absolute optimum, get close enough to it in practical terms. An example is shown in Fig.8. The output file can then be transmitted to automatic control of a cutting machine, Fig.9.

5. Commercial and Retail

Financial control, production planning and monitoring, stock control and delivery, and other commercial operations are obvious places for the use of digital technology, but these are mostly common to all industries. Two special features of the textile industries, which impact particularly on the retail market, are the diversity of products and the short time-scale from design to purchase. Contrast the changing range of garments and other textiles in a department store with the few models in a car showroom with change occurring over a period of years.

6. Engineering Design

The above three sections deal with digital technologies in common use in the textile industries today. Engineering design remains a challenge for commercial use. The mechanical properties of textile materials, along with other properties related to the particular application, are clearly important in technical uses. These properties also control the subjective aspects of textiles, such as comport and drape, which are discussed in the next section and are important for the consumer's appreciation of a garment.

In the 21st century, in almost the whole of engineering, computer aided design (CAD) is the norm for design of structures and prediction of performance. The textile industry is an exception. The reasons are partly technical. Products are made of millions of fibres with complicated visco-elastic-plastic properties and deformations are large and complex. These factors mean that the small-strain, linear-elastic approximations suitable for rigid structures are not applicable. However conservatism is at least an equal factor. Companies are mostly small and the staff have great practical experience and intuition. Traditional procedures are currently preferred. Nevertheless, in any application, digital technology has the potential for better optimisation, with fewer practical trials, greater efficiency, and enhanced fitness for purpose.

Customers in engineering organizations need to have the confidence that modern, quantitative CAD procedures have been used in the design of a product. A typical example is an aircraft engineer wishing to use a 3D fabric in a composite. In my experience, the only fibre use where this approach has been tried is in ropes – and that was fortuitously due to the needs of an organisation with the resources to pay for the development. The US Navy has long wished to develop a large floating platform that

a) b) c) d)

Fig.10 Weave geometry: a) point paper; b) mesh; c) with yarn shapes; d) algorithm for yarn shapes with and without transverse forces

could be used as an airfield and military base moored where it was needed at any time. In the late 1980s, the Naval Civil Engineering Laboratory, which was working on how to moor a platform in deep water, asked the newly formed consultancy, Tension Technology International (TTI), to develop a rope modeling program. This eventually led to Fibre Rope Modeller (FRM), which is now used to some extent in the ropemaking industry.

Academic studies on the structural mechanics of textiles go back a hundred years. Following a paper on cotton yarns by Gegauff in 1907 and by Haas in 1912 on woven fabrics, occasional papers appeared until the mid-1940s. Then Fabric Research Laboratories in Boston initiated the present period of continuous research. The mechanics of twisted, continuous filament yarns illustrates the changing methodology. Even large yarn extensions can be related to fibre extension by a simple geometrical equation. In the first model, components of the fibre tensions were summed. In order to account for the transverse forces between fibres, equilibrium of forces was used, but the mathematics became increasingly complicated for large strains and nonlinear fibre properties. Treloar's work on tyre cords was a breakthrough: conservation of energy is simpler and has fewer limitations. A few simple equations can be programmed. Spun yarns from short fibres are more complicated. For such yarns, it would probably be best not to try to model the detailed fibre arrangement but to have a data base of measured properties with semi-empirical relations to predict the effect of changes in the yarns, namely fibre content, linear density, twist, etc.

For woven fabrics (similar principles apply to braids and, taking account of loop structures, to knits), the topology was traditionally specified by the binary means of point paper, Fig.10a. On a computer, mesh graphics, Fig.10b, is more informative; clicking on a crossover changes whether warp or weft is on top. If yarn spacings and shape are known, more realism can be achieved, Fig.10c. Circular, race track and lenticular forms have been used to define yarn shapes, but a more promising way of specifying yarn cross-sections under the forces at crossovers is the vector method developed by Jiang and Chen [2].

As with yarns, the early work on woven fabric mechanics used force and moment methods. In 1978, Hearle and Shanahan [3] proposed an energy method, which is a more versatile and powerful procedure. This has been further developed in recent work. A fabric element is defined by major control points at the corners of a repeating element, which will contain minor control points at each crossover. In a first approximation, the minor control points are assumed to deform affinely with respect to the major control points. We then have:

total deformation energy =
= Σ[yarn (extension + bending +
+ flattening) energy]

The length, bending curve and yarn shape at and between the minor control pints interact with each other. Minimisation determines their values. The differences between the total energies due to increments of deformation enable the forces generated in the fabric to be determined.

Variants of this energy approach are in Weave GeoModeller from TexEng Software Ltd, TexGen from Nottingham University, and WiseTex from Leuven University, but there has been little, if any, commercial use. It would be beneficial to use the diverse facilities of widely used finite element analysis programs such as ABAQUS and others. In my view, the better known methods using 3D solid elements are not well suited to the structural mechanics of fabrics. The lesser known beam model is more suited to structures composed of flexible linear elements, such as fibres and yarns.

In contrast to the work on ropes, which was further driven by the needs of oil companies mooring rigs in deep water with polyester ropes, modelling of fabric mechanics has been by academic push not demand pull. It still seems necessary to show what could be done before industry asks for programs that will take them into 21st century CAD. The basic knowledge to develop software exists. A strong effort is needed to convert it to commercial software. What can be done from the push side to encourage pull from the industry Three points are inter-related. (1) Try to identify useful simplifications, rather than produce universal software. Two special cases are fabrics with monofil or hard twisted yarns where shape change is negligible and fabrics with soft yarns where there is no free length between crossovers. (2) Concentrate on programs related to specific problems, rather than aiming for universal applicability. (3) Try to find clients who have a special and immediate need.

7. A Full Link to the Consumer Market

For purely technical textile markets, the requirements of the products can usually be expressed in terms that are easily understood by engineers, physicists or chemists. Qualitatively, the scientific links are mostly clear, though there is a challenge in converting the complexities into a viable analytical and computational model. For some applications, it will be necessary to devise experimental procedures to provide the input data for "unknown" fibre properties, such as the rate of wear of fibres as they rub against each other.

For what most people regard as the textile market, there is no clear terminology to use. We can refer to consumer textiles, fashion goods or, more explicitly, to clothing, furnishings etc. In these markets, individuals are making aesthetic, sensual, psychological choices on what to buy and wear or use. There are technical requirements, such as opacity to screen the body or block windows and heat-and-moisture transfer to control comfort, though this introduces a subjective feature that is not easily quantifiable. In some requirements such as active or protective clothing, there are functionality requirements, which may even outweigh considerations of "fashion". However usually aesthetics dominates.

For colour and pattern, the way to introduce digital technology is simple. The visual appearance of textured fabric surfaces is somewhat more difficult, but is a clear technical problem that does not require any deep understanding of textile materials. The major challenge is how fabrics drape either statically at rest or dynamically with movement. This is also a problem in some technical uses; for example, how can a fabric be draped or forced over a mould (an ashtray is sometimes used in trials) before impregnation to form a composite. The science, which determines the forms, has not been well worked out.

The holy grail of this aspect of digital technology is the "virtual catwalk" in which "models" could be seen walking down a catwalk as realistically as at a real fashion show – or where a customer can walk into a shop or go on-line at home, select an item from a collection of pictures, and then view on a screen how they would look as they wore the garment and moved around in different environments and lighting conditions, a true virtual reality. The practicalities would include simple ways of making choices such as changing colour, choosing a different fabric for a dress or even making greater design changes.

There has been progress, though limited, if any, commercial application, in one aspect of this retail vision. Bespoke garments, where the tailor or dressmaker, measures the customer and makes a suit or a dress to fit, can be replaced by body scanning with digital information transmitted to the factory to change the control of the cutting plan to fit the customer. No-one has found a way to demonstrate the visual aesthetics to a standard expected from what is seen in films or on TV.

There are three levels of virtual reality. For cartoons, distortion, "unreality", is acceptable, even advantageous. For TV and films, there have been amazing advances in virtual imaging. However, what is needed is simply to give the viewer a true-to-life appearance of reality. This is purely a matter of computer graphics, brilliant but not related to real materials. The problem posed for the textile and clothing industries is an order of magnitude more difficult, relating the appearance to the actual physical properties of a textile fabric.

There have been approaches to this problem using finite element or finite particle methods to minimize deformation over the whole area of a planar fabric. One of the earliest was in 1994 by Breen et al [4]. An example, which involved a long computing time, is shown in Fig.11. The appearance is reasonable for it is a very simple form of drape and does not involve the multiple buckling found in clothes. Other researchers have added movement, but none match the quality that a viewer would expect.

I believe that there are two issues.

Organisationally, the approaches have typically been by teams that are little more than one academic and a research assistant. To match the appearance in films, which is what a consumer would expect to see, there is a need for vastly bigger and committed effort, involving experts in computer graphics interacting with people who understand textile mechanics and others who understand the fashion and retail markets.

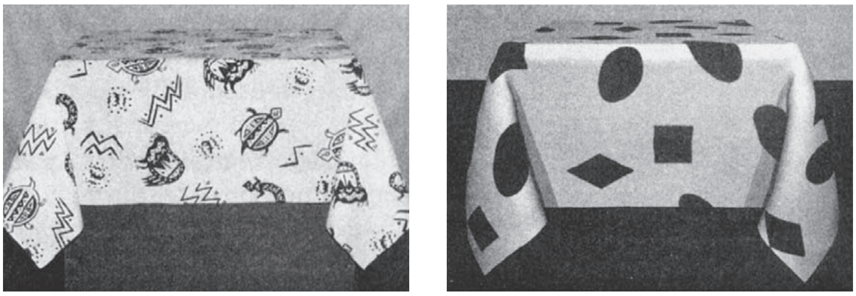
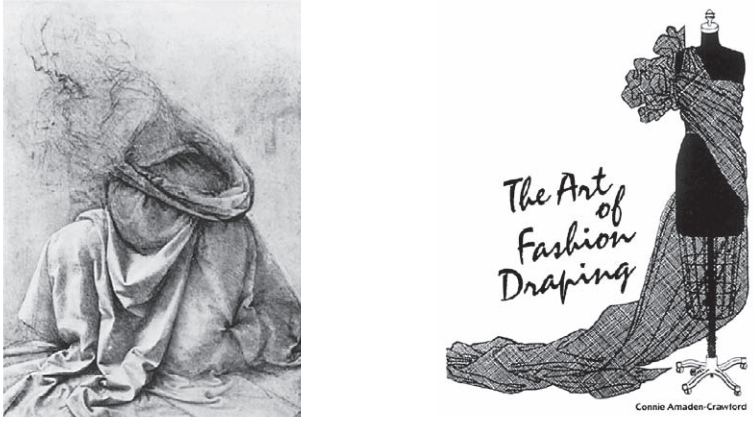

a) b)

Fig.11 Prediction of fabric drape: a) real; b) simulated

Technically, I believe that there is a need to look more closely at the 3D buckling of fabrics and how this should best be modeled. The complex buckling of fabrics has long been a concern of artists, Fig.12a, and seen as an art, Fig.12b. In contrast to the sharp points formed when paper is crushed, research in the 1960s [5] showed that the rounded three-dimensional forms of buckling in double curvature depended not only on low bending stiffness but also on low shear resistance. Later studies by Hearle and Amirbayat [6, 7] showed that three-fold buckling was a common form, Fig.13a. There is a rounded dome of double curvature at the centre and folds of double curvature at the edges. An analysis for a linear-elastic, isotropic material showed this form, Fig.13b, but more work is needed for computation for fabrics, which are anisotropic with non-linear mechanical properties. Two other forms of buckling appear: one is straight buckling along warp or weft; the other is the long diagonal buckles formed when tension is applied in the bias direction of a fabric and seen, for example, on trousers over the thigh. These features should be taken into account in validating any software. It is possible that they might be invoked in developing clever algorithms as an alternative to the "brute force" procedure of finite element models over a whole garment. The role of seams also needs to be taken into account.

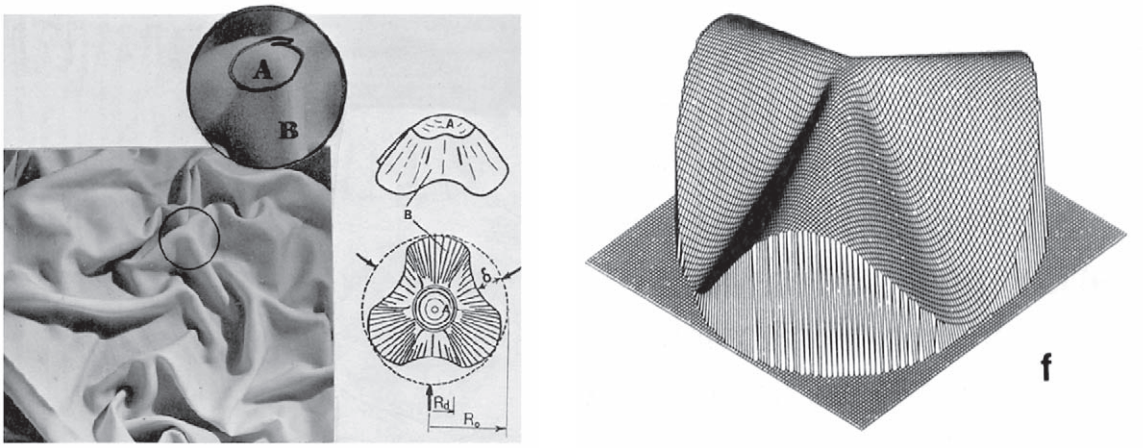
Whatever program is developed, there are basic mechanical principles to take into account:

- The relation between extension and bending. In solid materials, bending stiffness is related to tensile stiffness by the parameter *EI* where *E* is Young's modulus and *I* has the form of a moment of inertia. In contrast to this, there is no direct relation between tensile stiffness and bending stiffness in a structure such as a textile fabric.
- Anisotropy. In a fabric, six directions must be considered. This leads to a matrix of elastic constants, Fig.14a, and analogous relations for large-strain non-linearity. The suffixes 1 and 2 relate to in-plane tension/extension in warp and weft directions, and 3 to moment/shear. The suffixes 4 and 5 relate to moment/curvature in warp and weft directions. The direction 6 is often neglected and is not easily measured directly, but must be taken into account. It relates to moment/twisting and is analogous to the way in which extension on the diagonal can be related to the two tensile directions plus shear. Fig.14b shows how bending on the diagonal is related to the two bending directions plus twisting. Bending tests in three directions can provide the necessary information.



a) b)

Fig.12 a) Leonardo da Vinci's study of drape; b) cover of a book published in the 1990s

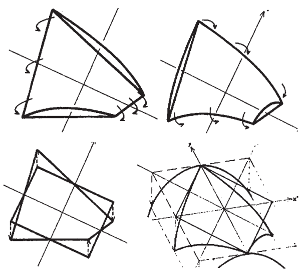


a) b)

Fig.13 a) Forms of three-fold buckling; b) computed model for a simple material, From Hearle and Amibayat [4] and Hearle [5]

$$\begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & B_{14} & B_{15} & B_{16} \\ & A_{22} & A_{23} & B_{24} & B_{25} & B_{26} \\ & & A_{33} & B_{34} & B_{35} & B_{36} \\ & & & D_{44} & D_{45} & D_{46} \\ & \text{symmetrical} & & & D_{55} & D_{56} \\ & & & & & D_{66} \end{bmatrix} \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \end{bmatrix}$$

a)



b)

Fig.14 a) Matrix of elastic constants, b) two bends and a twist give bending on the diagonal. From Shanahan et al [8]

- Interaction in stiffness between directions. The matrix in Fig.14a shows that the various directions are inter-related. For example, bending stiffness will depend on fabric tension. There may be simplifications for modeling: at high tensions, bending will be negligible.
- Simple geometric interactions between directions. The Poisson's ratio effect, lateral contraction linked to axial extension is well known and length changes are also associated with shear. The out-of-plane effects are less clear.
- Non-uniformity of deformation. A simple test of the twisting mode would clamp both ends of a sample and twist it. If the distance between the clamps is fixed, there will be no change of length at the centre but increasing length towards the edges.
- Compression. Where a fabric is pulled tight over a solid surface, for example as a trouser crosses the knee, the out-of-plane deformation will be determined by the shape of the surface. However forces will be transmitted to free areas and friction will play a part.
- Dynamics. Solving the static form of draping is only the start of the problem. The movement of fabrics will depend upon inertia and will be affected by the passive influence of air resistance and the active influence of wind forces.

Clearly the problems are complex and justify the comment above that a large and diverse team is needed to develop software for the virtual catwalk and virtual shopping, either in a store or on-line. The work will include experimental studies for understanding and validation, development of test methods (or, less likely, modelling from fibre to yarn to fabric) to give fabric properties for on-line input to modelling, geometrical and mechanical analysis, programming and display in a way that is efficient and meets the needs of the user. I am not sure that I will see this in my lifetime, but expect it to be there before the end of the century. The continued increased in computer power will make the task easier.

8. Other Thoughts

There has been little use of digital technology to model processes. This would have been useful years ago when major advances were being made in the production of regenerated and synthetic fibres and when new machines and processes were being introduced for spinning and weaving. However these are now more stable technologies. Most of what has been done relates to the machines themselves. Few studies involve interaction with the fibres. For example the simulation of air-jet spinning by Pei and Yu [9], Fig.15, is solely concerned with air-flow. There are exceptions, For example, Overington [10] simulated the false twist texturing process.

Most previous studies of structural mechanics have used generalised paths for fibres in yarns and yarns in fabrics. Increased computing power means that it is now possible to model individual fibre elements. Examples are research on carpet wear [10] and the movement of fibres in assemblies that leads to pilling [11]. Following individual fibre elements would have allowed the artificial seven-ply model of fibre migration in yarns from 1962 [12] to be applied to the actual response of the many fibres moving through the delta in yarn spinning and changing their position in the yarn. Maybe, digital modelling would be useful in dealing with the problems of converting electrospun nanofibres and carbon nanotubes into yarns.

9. Conclusion

In *The Observer* newspaper of 20-4-14, the IT columnist, John Naughton reviewed *The People's Platform: Taking Back Power and Culture in the Digital Age* by Astra Taylor and made the following comments.

> For the first 20 years of the evolution of the internet — from the start of the "internetworking" project in 1973 to the launch of the first major web browser in 1993 - cyberspace (the virtual world behind the

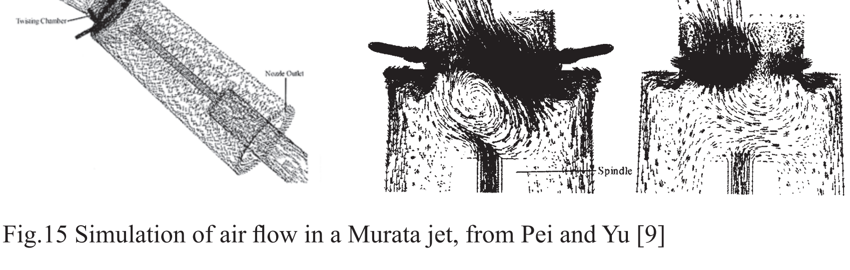


Fig.15 Simulation of air flow in a Murata jet, from Pei and Yu [9]

Fig.16 An oil rig

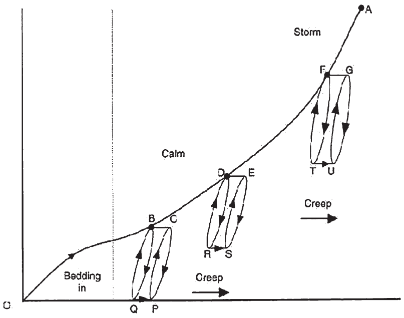


Fig.17 Polyester rope load-extension properties

screen, as William Gibson put it) and “meatspace” (John Perry Barlow’s term for the material world) were, effectively, parallel universes. Cyberspace was the preserve of a privileged elite - the computer students who collaboratively designed and had access to it. And the inhabitants of meatspace were, for the most part, blissfully unaware of its existence.

The two universes were radically different. For the netizens of cyberspace, meatspace - the world dominated by “weary giants of flesh and steel”, declared Barlow - had purchased a one-way ticket to the dustbin of history. Netizens believed that the internet was about to “flatten organisations, globalise society, decentralise control, and help harmonise people”, as Nicholas Negroponte, the MIT guru, put it.

This strikes a chord with what I have described in this paper. The textile and fashion designers, the machine designers and the commercial world have moved into the cyberspace. But textile design for mechanical and other physical performance requirements, whether for clothes or technical textiles, has stuck in the meatspace. Meanwhile, retailers would love to move consumer choice from meatspace to cyberspace, but the entrepreneurs and the computer coders, who inhabit places like Silicon Valley and operate at less cost in places like Bangalore, have not formed a creative partnership with those of us who understand something of the complexities of textile mechanics.

It is interesting that Naughton puts the start of his story in 1973, because that is around the time that we saw the start of the revolution through the application of digital technology in fabric and fashion design, in machine control and in commercial activities, such as stock control and “make-and-supply on demand. In other ways, the textile industry has lagged behind other industries. For technical applications, the old methods, based on practical experience, intuition and trial-and-error, still prevail. CAD to design structures and predict performance is hardly used; the only exception that I know of is Fibre Rope Modeller. There are no commercial programs available in the way that finite element and other packages are available for other engineers. The academic basis is known, but there has not been the will in industry to demand its application in easy-to-use software. If this software could be developed, it would open the way to dealing with the more difficult problems of the subjective impression of textiles for the fashion market.

How can we move technical textile design into 21st century culture? Basic academic research can provide some answers, but the experience of 70 years of continuous research on the structural mechanics of textiles shows that this is not enough. I believe that progress will come from well-focussed attacks on particular needs where there can be interaction between the needs of the user and the skills of the programmer. What is not the best way is shown by a recent project, Multi-Scale Integrated Modelling for High Performance Flexible Materials. Supported by a UK government grant and involving a number of companies, with interests ranging from chemistry to mechanics, airbags to expnsive men’s suits, and laundering to super computers, it aimed to provide integrated software covering the technology from fibres through yarns and fabrics to final products including an approach to the virtual catwalk – with the detailed research being carried out by just three research assistants located in three different Universities!

As a final comment, I will refer to a link between the rope industry, which operates in the traditional, practical way of most textile companies, and marine engineers. The problem was mooring oil-rigs, Fig.16. Steel wire ropes were being used for depths down to 500 meters. In the late 1980s, oil companies wanted to extract oil from depths greater than 1000 metres. Conventional wire-rope, catenary moorings were too heavy and would generate tensions too close to or greater than the rope break load. Taut fibre rope moorings were needed. Somwhat to the surprise of the oil companies, the right performance was not given by the new high-tenacity fibres such as aramids or HMPE, but by polyester ropes. Engineers were not used to dealing with the non-linear, viscoelastic, high elongation properties of polymer fibres. TTI had to propose ways in which the complicated mechanical properties of a polyeater rope, Fig.17, could be input to the digital mooring programs used by marine engineers to predict tensions and drift under a variety of sea and wind conditions. , The software had to be modified for taut moorings and simplified digital inputs used for different conditions. The benefits of digital technology made possible the interaction between engineers and those of us who understood fibres and ropes.

The final outcome was an engineers' design guide to deepwater moorings [13]. Maybe one day, there will be a fashion designer's guide to the apperance of a model walking down the catwalk in a glamorous gown. The textile and clothing industries will have completed the journey from meatspace to cyberspace.

References:

[1] Backer S.: An engineering approach to textile structures, Chapter 1, In Structural Mechanics of Fibers, Yarns and Fabrics, Wiley-Interscience, New York, (1969), Vol. 1

[2] Jiang Y., X. Chen: Geometric and algebraic algorithms for modelling yarn in woven fabrics, Journal of the Textile Institute 96 (2005) 8, pp. 237-246, ISSN 0040-5000

[3] Hearle J.W.S., W.J. Shanahan: An energy method for calculations in fabric mechanics. Part I. Principles of the method. Part II. Examples of the application of the method to woven fabrics, Journal of the Textile Institute 69 (1978) 4, pp. 81-91, 92-100, ISSN 0040-5000

[4] Breen D.E., D.H. House, M.J. Wozny: A particle-based model for simulating the draping behavior of woven cloth, Textile Research Journal 64 (1994) 11, pp. 663-685, ISSN 0040-5175

[5] Hearle J.W.S.: Shear and Drape of Fabrics, Chapter 12, in Structural Mechanics of Fibers, Yarns and Fabrics, Wiley-Interscience, New York, (1969), Vol. 1

[6] Hearle J.W.S., J. Amirbayat: The complex buckling of textile materials. Part I. Theoretical approach. Part II. Experimental study of threefold buckling, International Journal of Mechanical Sciences 28 (1986) 6, pp. 339-358, 359-370, ISSN 0020-7403

[7] Hearle J.W.S., J. Amirbayat: The anatomy of buckling of textile fabrics: drape and conformability, Journal of the Textile Institute 80 (1989) 1, pp. 51-70, ISSN 0040-5000

[8] Shanahan W.J., D.W. Lloyd, J.W.S. Hearle: Characterising the elastic behaviour of textile fabrics in complex deformation, Textile Research Journal 48 (1978) 5, pp. 495-505, ISSN 0040-5175

[9] Pei Z., C. Yu: Study on the principle of yarn formation of Murata vortex spinning using numerical simulation, Textile Research Journal 79 (2009) 14, pp.1274-1280, ISSN 0040-5175

[10] Hearle J.W.S. et al: Computational model of wool carpet wear, Journal of the Textile Institute 96 (2005) 2, pp. 137-142, ISSN 0040-5000

[11] Hearle J.W.S., A.H. Wilkins: Mechanistic modelling of pilling. Part I, Detailing of mechanisms. Part II. Individual fibre computational model, Journal of the Textile Institute 97 (2006) 4, pp. 359-368, 369-376, ISSN 0040-5000

[12] Hearle J.W.S., V.B. Merchant: Interchange of position among the components of a 7-ply structure: mechanism of migration, Journal of the Textile Institute 53 (1962), T537-T552, ISSN 0040-5000

[13] Tension Technology International and Noble Denton, Deepwater Fibre Moorings – an engineers' design guide, Oilfield Publications Ltd, Ledburt, UK, 1999.