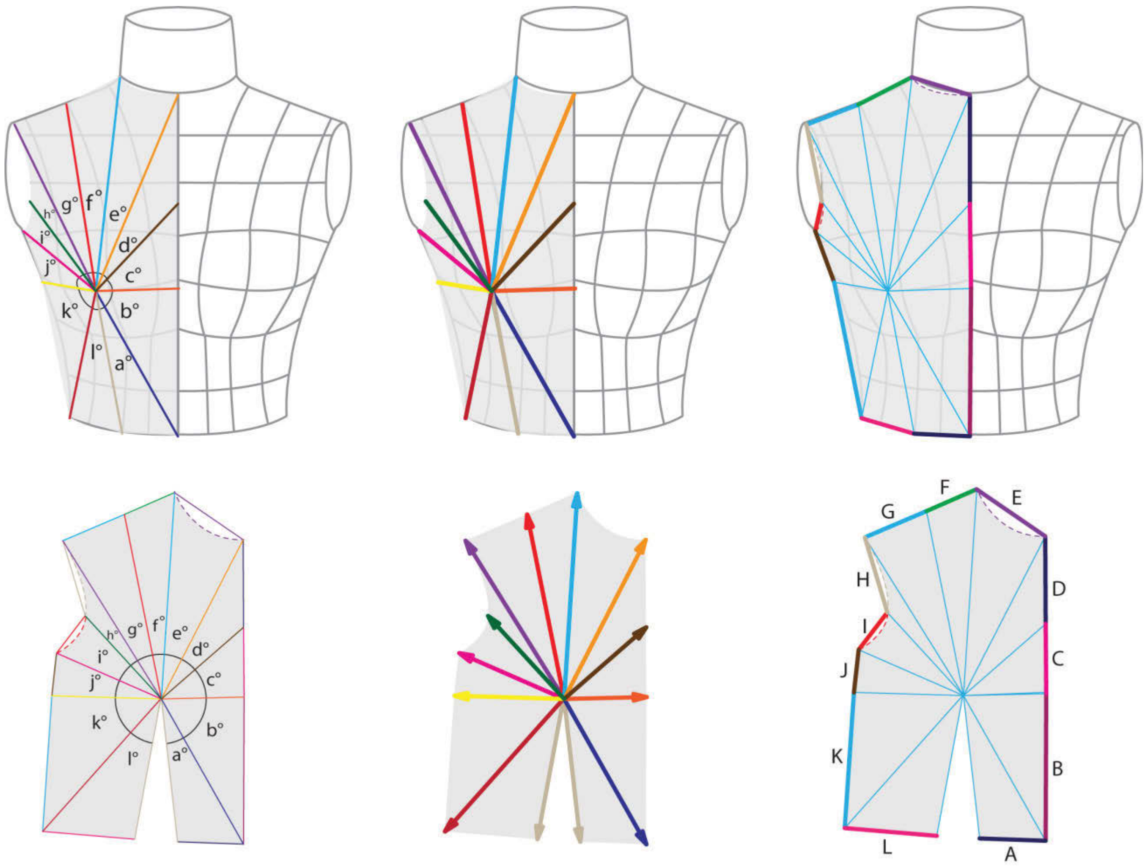
Fashioning Geometric Patterns:

Investigating the underlying geometry of fashion patternmaking



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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree, nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

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ABOUT THE AUTHOR

Mark Liu is a fashion and textile designer dedicated to advancing scientific principles in the application of traditional techniques. He is noted for pioneering the area of Zero-Waste Fashion design in the sustainable fashion movement in London (Bierhals 2008, p. 58, Parish 2012 pp. 164 - 165). Mark ran a Zero-Waste Fashion label for several years and has exhibited in Estethica at London Fashion Week for many seasons. This fashion label was awarded the Innovation Award in the Ethical Fashion Forum. Mark was awarded the role of artist-in-residence at the London Print Works Trust. He has been a keynote speaker on sustainable fashion, at events such as the "Beyond Green" Conference in Amsterdam. His work bridging the gap between fashion and science has showcased at the London Science Museum. Mark's commissions have taken him all over the world, including representing the British Council in a sustainable fashion show in New Delhi, and creating collections for the Gyeonggi Museum of Modern Art in Korea. His work has exhibited in museums in the UK, US, China, India, Korea, Amsterdam and Denmark, and has been published in numerous newspapers, magazines, books, publications and blogs.

Mark achieved a bachelor's degree in Design (Fashion and Textiles) with First Class honours at the University of Technology Sydney, writing his thesis on the "Implications of Nanotechnology Textiles on Fashion Product and Lifestyle Trends". While at University he won the Oroton Award Scholarship, as well as interning at the fashion label Marcs. On graduation he won first place in the Oroton Graduate Award. Following graduation he worked as a textile consultant for Signature Prints.

Mark moved to London in 2005 and completed a Masters of Textiles Futures at Central Saint Martins College. He also attended the New Creative Ventures course at London Business School. While attending college he interned at fashion labels such as Alexander McQueen, Ghost and Miss

Selfridge. He wrote his masters thesis addressing the proposition "Can the process of engineering textile designs into fashion pattern-cutting create innovation in fashion design?". This research would become the basis for Mark's jigsaw patternmaking technique of zero-waste fashion patternmaking. In consequence, after graduation he was invited to show in London Fashion Week and started a zero-waste fashion label.

Mark has systematically investigated the sciences for knowledge and technologies that will re-invent fashion practises and create systemic change in the fashion industry. He has zealously implemented mathematical concepts in conventional fashion patternmaking and zero-waste patternmaking, while he continues to explore unconventional approaches to garment construction. These approaches include growing textiles from bacteria, creating bioplastics, and developing methods for digitally printing on curved three-dimensional fabric surfaces.

In recent times, while researching his PhD Mark has served as a lecturer at the University of Technology Sydney and has helped to write components of the Masters of Design course.

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Figure 1	A variable pattern transforms between different states over time.
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Experiment 76	**A network**
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ABSTRACT

This thesis seeks to apply mathematic principles to traditional fashion patternmaking. The goal is to understand core practices from a fresh perspective and to propose strategies to address systemic inaccuracies identified by patternmaking experts. In the course of seventy-seven systematic experiments, we test traditional techniques within a rigorous geometric framework. In doing so we confront the systemic reliance on linear measurement, that is fundamentally incapable of measuring the body's complex curvature. Experts repeatedly point to the inadequacy of drafting from such means, and of the heavy reliance on personal judgement. Non-Euclidean geometry is established as the mathematics that governs curved surfaces, and our research builds a new fashion patternmaking system based on its principles. By its use we compare the limitations of traditional Euclidean linear measurement in describing complex curved surfaces, and thereby promote new techniques to boost levels of accuracy, efficiency and creative freedom. Our research analyses and maps the shape of the body in time as a series of patterns that seek to capture body movement, and in turn seeks to build garments that anticipate that movement. We thereby introduce a new generation of 'variable structures' and 'smart patterns' designed to change shape in time, leading to improved fit, function and aesthetic.

Patternmaking is ubiquitous in the modern fashion industry, and our work has pressing applications from fast fashion to high fashion. We offer real commercial benefits in time, labour and materials efficiently conserved. We bridge the gap between patternmaking and engineering that underpins the development of software applications, notably the mapping of time-based 4D scans to generate advanced patterns. In sum, our techniques seek to empower the modern fashion designer to express their creativity and build new generations of fashion garments.

INTRODUCTION

This thesis seeks to apply mathematical principles to fashion patternmaking techniques with the goal of fundamentally overhauling how they are applied. In particular, our[1] thesis demonstrates how geometry offers a scientific framework for fashion patternmaking, replacing age-old reliance on subjective experience and anecdotal evidence. Fashion patternmakers and technologists are aware that patternmaking techniques are limited in their accuracy and often rely on the judgement of the patternmaker to solve fitting problems. Our application of a geometric perspective readily explains why some existing techniques are reliably accurate and why others are limited in accuracy. The thesis thereby offers a series of systematic experiments that test existing patternmaking techniques to better understand their limitations. While we note that the field of mathematics has foreshadowed solutions for many of the geometric problems that patternmakers encounter, we now assert that adopting geometric principles in fashion patternmaking allows us to invent specific patternmaking techniques and methodologies. Such techniques offer patternmakers greater control than ever before, enabling creative possibilities that are both exciting and efficiently replicable. In fact, our research deconstructs the traditional craft of patternmaking (which had barely changed in the last hundred years) and literally re-invents it with geometry-based techniques. The result is that we have significantly systematised and expanded the creative possibilities of fashion design.

Fashion Patternmaking is the art of shaping flat pieces of cloth into three-dimensional shaped clothing, determining the look, fit and feel of every fashion garment. Patternmaking is a crucial component of fashion for both functional and aesthetic purposes, and we underestimate its

[1] The research uses the terms “We” or “Our” to refer to the researcher Mark Liu who has been conducting research at the University of Technology Sydney from 2010 to 2015.

significance at our peril. While patternmaking may seem like a well-understood traditional craft, underlying its techniques is a complex series of processes which still challenge fashion technologists. Modern patternmaking may employ computer programs and advanced technology, but these essentially automate the same techniques and principles used by traditional patternmakers.

Historically, the form clothing takes is determined by the technology, materials and ideas available at the time. While many researches try to advance fashion through new materials and technology, our research takes a different approach. It focuses on improving the methods underlying patternmaking techniques. By introducing modern mathematics it aims to better understand traditional techniques and develop methods based on geometric principles.

Every tradition that modern fashion designers take for granted was once a radical new invention. Inventions are naturally desirable as they bypass the limitations of previous techniques; yet while every invention creates new possibilities, it inevitably leads to limitations. In this light, the goal of research in this thesis is to create a mathematically precise patternmaking system that sets a benchmark for patternmakers to continue to realise new creative possibilities.

Using mathematics to explain and enhance traditional fashion patternmaking techniques is indeed rich with opportunities. This mathematical thrust was inspired by the rapid technological advancement in modern origami. Recently the ancient art of paper-folding made a technological leap when mathematicians began to study its underlying processes. Mathematical concepts of geometry, topology and sphere packing were able to explain how traditional techniques worked. This established a field of study called "Origamics", which offered new applications for mathematicians, engineers and scientists as well as origami artists. Mathematicians such as Demaine (2007) and Lang (2003) created mathematical proofs and wrote software to automate their discoveries. In turn, deeper understanding of origami enabled modern artists to build creations with greater levels of sophistication, indeed to rapidly create complex origami that might take the traditional artist several lifetimes to work out by trial and error. For example instead of creating a shape that symbolised a fish, they could build a realistic fish with thousands of scales. Thus, by analysing a traditional practise using a mathematical framework it was possible to rapidly evolve an ancient art into a modern science.

Historically, the scientific community is familiar with the phenomenon whereby a traditional craft is developed over time into a rigorous scientific process. The mathematics of geometry itself in 600 BCE was once no more than a crude set of techniques used to survey land, yet mathematical discoveries from ancient Greek mathematicians such as Thales and Pythagoras developed geometry into a deductive system of thought based on mathematical proof (Trudeau 1987, pp. 1 - 2). Further, the Nobel Prize-winning physicist Eugene Wigner describes a process where scientific or technological advancement is often achieved when physical phenomena are explained in terms of mathematics (Wigner, 1960). Understanding the underlying mathematics of a physical process allows ideas to be manipulated conceptually instead of tested physically by trial and error. This increases the speed with which knowledge can be manipulated, and often leads to technological advancement.

There is substantial room for improvement in fashion patternmaking, such that many prominent fashion technologists and fashion patternmakers have identified problems with existing techniques. And even though technology has greatly advanced, the underlying principles of fashion patternmaking have remained the same (Chen 1998, ch. 2 p. 36). Most problems stem from the notion that patternmaking systems are more like guidelines - that rely on the judgement and intuition of the patternmaker to make them work. Experts are critical of how even the best patterns are approximations and have to be tested by trial and error (Kwong 2004, p. 196). A system that is subjective, that relies solely on the intuition and experience of the patternmaker, is clearly inconsistent. Traditional patternmaking continues to perceive intuition as a virtuosic skill that is much too subjective to be explained or quantified. Such reliance on subjectivity has made it difficult to automate parts of the fashion patternmaking process.

The intangible nature of intuition has made the nuances of skilled patternmakers difficult to discuss. It is true that intuition can often fill in many of the missing steps of a formalised patternmaking system, and it is easy to mythologize the skills of exceptional patternmakers. Nonetheless, the scientific community has developed rigorous approaches to the analysis of intuition. Nobel prizewinning psychologist Daniel Kahneman has researched the psychological mechanisms responsible for judgement and expert intuition. His work demystifies the mythology of expert intuition by revealing that heuristics or rules of thumb are simply processes of pattern recognition (Kahneman 2011, p. 11). Kahneman's research further reveals that rapid intuitive thinking involves innate bias and creates systematic errors (Kahneman 2011, p. 3 - 4). Over time the idea that intuition is susceptible to systematic error or bias has been generally accepted by the scientific community, and this finding is used by scholars in many different fields (Kahneman 2011, p. 10). There is no reason why this approach could not be applied to fashion patternmaking.

To view patternmaking from a scientific perspective can address many of the problems that fashion technologists identify in patternmaking systems. Some are critical of how techniques that use linear measurements are unable to map the complex three-dimensional form of the body (Whife 1965, pp. 1 - 16). Others criticise the inherent subjectivity of taking measurements off the body – that it is more art than science (Watkins 1995, p. 268). There is also an objection that patternmaking techniques have limited ability to fit people with non-standard body types (Whife 2011, p. 247). Sizing systems used in ready-to-wear are based on linear measurements, and the problem whereby ready-to-wear clothing does not fit many customers pervades the supply-chain process (Otieno 2008, p. 73).

Within patternmaking itself there are many different systems with divergent approaches to patternmaking. At the same time there is a dearth of books that address how patternmaking fundamentally works (Newton 1986, cited in Chen 1998, ch. 2 p. 36). Granted, there are companion books written by patternmakers offering a guide of how to fit clothing to the body in different scenarios (Liechty *et al*. 2010, pp. 117 - 120), but these works in toto do little to form a rigorous scientific framework.

Many fashion technologists and patternmaking experts point to the need to develop new techniques with a more scientific framework. Some describe how empirical pattern construction methods have emerged to speed up the fashion production process, and that they were achieved within the technology of their time. Yet this approach is inappropriate for modern technology and it is time to re-examine these fitting methodologies (Watkins 2011, p. 245). Other experts describe the importance of establishing a scientific relationship between body shape and pattern shape (Efrat 1982, p. 35). There is also a perception that new technology such as three-dimensional scanners and sophisticated computer algorithms can solve many fitting problems (Kwong 2004, pp. 206 - 225). Although the use of three-dimensional software to create clothing is gaining attention in the media, there are significant problems involved in reverse-engineering pattern pieces into real world garments (Watkins 2011, p. 245).

Fashion Patternmaking meets Non-Euclidean Geometry

It is time to use modern mathematics to explain traditional fashion patternmaking techniques, time to explain the underlying phenomenon of patternmaking from a geometric perspective. Bypassing the confusion of multiple patternmaking systems using diverse sets of rules, we should move to unify the different systems of patternmaking under a single system of mathematic principles.

Non-Euclidean geometry is a form of mathematics that can describe curved three-dimensional surfaces. It emerged in the 19^{th} century and ran counter to the established view of Euclidean geometry promoted by ancient Greek mathematicians for thousands of years. Euclidean geometry uses a set of theorems (logical arguments) based on axioms (self-evident assumptions) to describe the mathematical properties of surfaces. For all this, it is limited in its ability to describe curved surfaces. Non-Euclidean geometry posits entirely different sets of rules that are logically consistent in describing curved surfaces. Flat surfaces have zero curvature while curved surfaces may have positive or negative curvature. As things stand, modern mathematics can use a combination of Euclidean and Non-Euclidean geometry to describe three-dimensional shapes.

The field of Non-Euclidean geometry encompasses a way of thinking that can address many of the problems fashion patternmakers encounter. Put simply, it has vast applications when applied to fashion patternmaking. Non-Euclidean geometry was developed by mathematicians such as Gauss, Bolyai and Lobachevsky in the 1830s. Before this time Euclidean geometry, that is, the mathematics of flat surfaces, was the only available form of mathematics. Subsequently, pioneers of Non-Euclidean geometry discovered that curved surfaces have a completely different set of geometric properties compared to Non-Euclidean Geometry (Taimina 2009, pp. 70 - 77). No doubt, when Non-Euclidean geometry was first proposed it was a revolutionary idea. Running counter as it did to the established view of Euclidean geometry established over thousands of years, it so counter-intuitively violated common-sense notions of space that many people considered it to be ridiculous (Tabak 2004, p. 88). Yet Euclidean geometry was always fundamentally limited in how accurately it could describe curved surfaces. Thereby, over time Non-Euclidean geometry became a necessity in mathematics.

Fundamentally, Non-Euclidean geometry forces mathematicians to consider the curvature of the surface. Different surfaces can have different geometric properties. Non-Euclidean geometry is able to describe spherical surfaces, called “spherical geometry” (see figure 1). It may also describe surfaces that are saddle-shaped, called “hyperbolic geometry” (see figure 1). Each of these curved surfaces possesses unique geometric rules that differ from flat “Euclidean” geometry (see figure 1). In general, from a geometric perspective we would require three different types of geometry to describe a complex curved surface such as the human body.

Fashion patternmaking principles are traditionally based on Euclidean geometry and use reasoning which is consistent within this paradigm. From a modern geometric perspective patternmaking techniques still use Euclidean principles to measure the curved Non-Euclidean shape of the human body, whereby measurements taken off a Non-Euclidean surface are then translated into flat Euclidean patterns. From a geometric perspective this approach is fundamentally limited because Euclidean geometry is limited in its ability to measure Non-Euclidean geometry. Using the logic of Euclidean geometry to measure a Non-Euclidean surface is inherently inconsistent. This explains why even the best patternmaking techniques are approximations which require the constant intervention of the patternmaker's intuition.

Non-Euclidean geometry by contrast offers a more sophisticated way to understand fashion patternmaking, introducing many concepts that make working with complex shapes easier to manage. The rules and logic of Non-Euclidean geometry differ completely from Euclidean geometry, and there are many new concepts required to address them. Moreover, it is essential to find the curvature of a surface because without knowing the curvature there is no way to understand which geometric rules govern it. Modern geometry also introduces new terms such as the "geodesic" to describe the shortest distance between two points of a curved surface. From a Non-Euclidean perspective, taking linear measurements off the body is rather meaningless without recording the curvature on which a geodesic lies.

Mathematicians had clearly paved the way with geometric ideas which could be adopted into fashion patternmaking, yet there are several reasons why Non-Euclidean geometry has eluded fashion patternmakers. Traditional 19th and 20th century fashion patternmakers may not have encountered Non-Euclidean geometry as it was not common knowledge at the time. Non-Euclidean geometry is a relatively new development in mathematics. Even at present, Non-Euclidean geometry is taught only at university level in mathematics degrees, while Euclidean geometry is taught in high school mathematics. The technical nature and complexity of Non-Euclidean geometry may also have deterred patternmakers.

There is also a significant gap between the pure mathematical principles of Non-Euclidean geometry and its practical application in patternmaking. Mathematics is full of calculations set in ideal scenarios, while patternmaking is always messy and "hands on". Certainly, commercial CAD software automates traditional patternmaking techniques, but it is still based on notions of Euclidean geometry. Computer scientists have likewise created computer algorithms to create flat patterns from three-dimensional scans. Such algorithms would require engineers to devise ways to flatten curved Non-Euclidean surfaces into flat patterns. Many three-dimensional algorithms generate patterns that are impractical to manufacture or neglect basic patternmaking considerations such as ease of use (Huang *et al.* 2012, pp. 680 – 683). What holds these technologies back is simply that the engineers and scientists who make the algorithms have no experience with making clothing.

The dependence on computers also takes patternmakers away from the hands-on tactile experience of making clothing. Patternmaking requires fabric to be draped and manipulated on the body, and this makes tactile techniques especially important. Practitioners use fabrics that stretch and wrinkle in unpredictable ways. They need simple techniques that are easy to use and that will facilitate their creativity. There needs to be a patternmaking system that has the rigour of Non-Euclidean geometry, but is so simple that patternmakers can use it while using pencils, scissors and paper. Such a system simply did not hitherto exist.

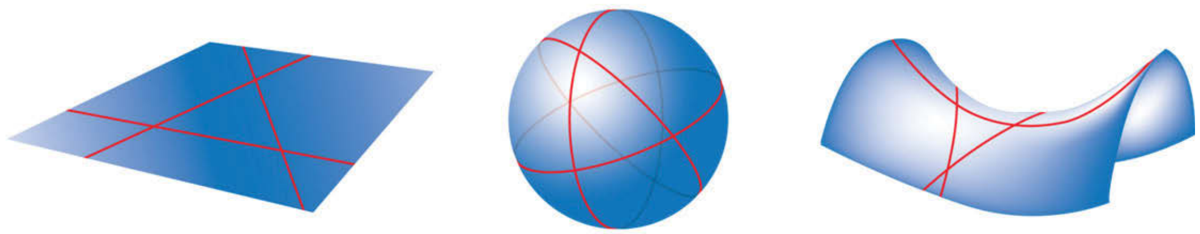


Figure 1: Euclidean Geometry and Non-Euclidean Geometry.

Applying modern mathematics to fashion patternmaking

There are numerous benefits to using modern mathematics to elucidate how traditional fashion patternmaking techniques work. Non-Euclidean geometry in particular explains many of the hidden complexities of fashion patternmaking. Creating a new patternmaking system based on geometry allows patternmakers to address many of the systemic problems in traditional patternmaking. Indeed, there are many patternmaking techniques that often have contradictory approaches. Geometry provides a way of unifying them all under a common language. This in turn can facilitate communication between different patternmakers. Traditionally a skilled patternmaker will rote-learn many different patternmaking procedures that each have their own rules and exceptions. By use of geometry the patternmaker simplifies the process merely through understanding the discipline's underlying principles.

A patternmaking system based on geometry will inevitably adopt techniques from Non-Euclidean geometry to secure more accurate measurements. Patternmakers are bound to conclude that factors such as the curvature of the body have as much importance as linear measurements on the body. Further, more accurate measurements lead to reduced trial and error fittings and increased accuracy. There are meanwhile key aspects of patternmaking that are heavily reliant on the patternmaker's intuition. For example, dart manipulations move style lines around the body while maintaining the same shape of garment. By contrast, to manipulate curved contours in the same way requires the continual intervention of the patternmaker. From a geometric perspective, these should be predictable geometric transformations that forfeit no geometric accuracy. In short, a geometry-based patternmaking system should make it easier to manipulate style lines in complex configurations while maintaining geometric accuracy.

Geometry-based patternmaking systems have the further potential to interface into modern fashion technology. At present the use of three-dimensional scanning technology to create accurately fitting patterns is still limited (Huang *et al.* 2012, pp. 680 – 683). A geometry-based patternmaking system could certainly be used to improve both traditional-pattern CAD programs and more advanced algorithms that turn three-dimensional scans into flat patterns. Thus, a patternmaking system based on Non-Euclidean principles would have the added advantage of being easier to implement into new technology.

This thesis asserts that a more rigorous patternmaking system allows patternmakers to better understand how body movement affects patterns, and that geometric patternmaking is uniquely placed to better map how the body changes shape over time with movement. While conventional patternmaking creates a pattern that would fit the body for a single instance in time, in reality the body is continually changing shape. The act of breathing, for example, constantly changes the shape of the chest, while eating alters the shape of the stomach. Again, changes in posture can completely reshape the entire body. It is clear that for a human body in constant flux, static patterns allow only a limited ability to fit clothing around that body.

While in the past patternmakers had very little control over how their patterns changed shape in time, the use of geometric patternmaking now makes it possible to map the range of human motion as a series of flat patterns. A conventional pattern is like a static photo of the body, while a dynamic pattern records the body as a series of images over time, like a strip of celluloid film. In other words, the dynamic pattern takes the invisible dimensions of time and movement and visualises them as a series of patterns. Mapping diverse body movements gives patternmakers a better understanding of how to create more sophisticated patterns, so that it is eminently possible to make patterns that anticipate and accommodate changing body movement. In turn, a deeper knowledge of patternmaking makes it possible to design patterns that change over time for different functional or aesthetic purposes. In short, to precisely design movement adds a crucial new dimension to patternmaking.

The notion of patterns that change shape over time has ushered in a new generation of patterns known as “variable structures”. Conventional patternmaking structures such as darts are of a single static shape. New variable structures such as “variable darts” could, for instance, open and close to change shape over time. Variable darts could be configured to respond to different body movements and thereby encompass different behaviours. This brings a new dimension of interactivity into fashion patternmaking. Variable structures have allowed patterns to be designed in configurations that intelligently change shape over time. These “smart patterns” are dynamic and introduce new creative possibilities. The very notion of fit is re-defined by smart garments that aim to fit the body as it changes shape over time. In sum, it is therefore possible for new smart patterns to address many of the systemic problems in conventional patternmaking created by movement.

The opening chapter of our thesis outlines the technological history that led to the development of modern fashion patternmaking techniques. The second chapter reviews the literature from expert patternmakers and fashion technologists who have identified limitations in existing fashion patternmaking techniques. The third chapter gives a brief history of Non-Euclidean geometry and a summary of the mathematical concepts that can be applied to fashion patternmaking. Following these chapters is a series of experiments that test new patternmaking concepts in relation to a range of traditional techniques. In total, we explore eighteen experimental sets, demonstrating techniques that offer powerful new possibilities and applications in fashion patternmaking.

CHAPTER 1

Technological History of Patternmaking

To view fashion history as a series of technical discoveries is inevitably to question the underlying assumptions on which our modern methods are built. Certainly, the technology of fashion patternmaking has a rich history of innovation and technological advancement, and over time innovations have become established traditions. It is important to remember that every established tradition was at some point a radical new invention. Thereby, in seeking to allow modern patternmakers to understand the fundamental problems that making clothing addresses, this chapter demands an investigation into the origins of many of the techniques that patternmakers take for granted.

Our thesis explores the underlying motivations for patternmaking and the divergent approaches to how clothing is best fitted to the body. We analyse the origins of measurement takers, patternmaking tools, fashion technology and materials. We address the implications of mass production, synthetic materials, anthropometrics and sizing systems. We also explain aspects of the development of our modern fashion industry, at the same time anticipating the impact of future materials and technology.

Fashion patternmaking is the process whereby shaped flat pieces of cloth are constructed into three-dimensional shaped clothing. The eminent fashion technologist Kwong describes the process of traditional making as follows:

> "Traditionally, pattern making in the apparel industry involves the process of obtaining the linear measurements over the body surface with a tape measure, and then applying these measurements to draft the pattern based on a mathematical foundation and approximation." (Kwong 2004, p. 196).

While Kwong's remark encapsulates key components required in fashion patternmaking, and is in fact a succinct description of patternmaking as it is relevant to modern patternmakers, yet his definition inspires us to examine the technological history of each part of the patternmaking process in far greater detail.

Kwong's definition describes traditional technologies such as tape measures, paper patterns, and patterns drafted from mathematical formulae. However, if one were for instance working in London before the second quarter of the nineteenth century, one would know that tape measures were not widely adopted (Efrat 1982, p. 4). According to the fashion technologist Efrat, prior to the tape measure, a device called a "measurement taker" was used. This was a long and narrow strip of parchment used to record measurements (1982, p. 4) that would be translated from the body directly onto the fabric of the garment (Efrat 1982, p. 3). Another version of the measurement taker was a string with knots tied onto it (Mathiassen *et al.* p. 58). An advantage of these earlier devices was that they allowed patternmakers who were not necessarily literate or numerate to draft patterns (Mathiassen *et al.* p. 58). They also did not require pen or paper. Prior to the 18th century, paper was a rare and relatively expensive product. The fashion technologist and patternmaker Chen remarks that it would not be until the 18th century that paper patterns and patterns drafted from mathematical formulae would become commonplace (Thornton & Moulton 1949, p. 15, cited in Chen 1998, ch. 2 p. 27). Examples such as this remind us that even today's entrenched traditions were once radical inventions.

Origins of Patternmaking

The process of making clothing is as old as civilisation itself. According to the fashion technologist Otieno the first clothes were thought to be made out of leaves, skin and tree barks (2008, p. 78). The fashion technologist Cooklin regards the origins of clothing as beginning with the discovery of the needle around 18,000 BCE (1997, p. 42). Efrat states "it is generally accepted that clothing was first worn before 2500 B.C. and since that time, man has always needed clothing." (1982, p. 3). The fashion historian Laver (2002, pp. 10 - 11) describes how early humans fashioned clothing made from animal pelts. Since pelts are problematic as they stiffen over time, and are irregular in shape (which leaves parts of the body exposed), treating the animal skin with fats and tannic acid from tree barks became a way to soften and shape the materials. Pelts thus treated could be cut and shaped. Combined with the invention of the needle, animal hides could then be sewn together and shaped around the human body. Such historical instances show that the need to cut shaped pieces of material to be sewn into a garment that fits the body is the essence of patternmaking.

The invention of woven material would advance clothing construction. Woven materials were initially of flax, originating around 4500 BCE (Efrat 1982, p. 3). This process of making cloth would establish the convention of fashioning materials in rectangular-shaped pieces. Early forms of clothing would rely on wrapping rectangles of cloth about the body (Laver 2002, p. 12), and historical traces of these technologies still exist in modern clothing, notably saris and sarongs. The development of technologies such as the loom would speed up the production of woven cloth and make clothing more accessible and elaborate. Civilizations such as the Egyptians, Assyrians, Greeks and Romans prided themselves on the elaborate way they draped their clothes (Laver 2002, p. 14). Garments such as the Roman toga epitomise the way fabric can be elaborately draped as a symbol or wealth, status and technological superiority (Laver 2002, p. 38). The Romans considered draped clothes to be the height of civilization, whereas tailored clothing was considered barbaric. The sacking of the Roman Empire in 410 AD by so-called “barbarians” (in this case the Visigoths) would spread new inventions such as trousers. The Visigoths wore trousers that allowed great mobility and were extremely practical for horse riding. The ability to make trousers was also a hallmark of the Persians that later spread to the Babylonians in the 6th Century BCE (Laver 2002, p. 15).

After the decline of the Roman Empire around the 5th century AD, clothing would become more fitted in style. The influence of techniques and materials from Middle Eastern and Asian cultures would advance patternmaking (Laver 2002, p. 15) such that garments would become much more fitted: a case in point is tunics and breaches developed in medieval times. New ideas such as the garment pattern were also introduced. The notion of drawing the flat pattern of a garment on a flat surface in order to replicate clothing was a novel one. The first evidence of patterns can be traced to 12th century Italian monks who used ideas bought from Greek and Jewish merchants (Thornton & Moulton 1949, p. 12, cited in Chen 1998, ch. 2 p. 26). These patterns were relatively crude, consisting of a back and sleeves. Patterns were generally written on slate, as paper at the time was unknown while parchment was too precious a commodity.

From medieval times up to the beginning of the nineteenth century, flat patterns cut to fit the different parts of the body were adopted (1998, ch. 2 p. 26). Over time the craft of tailoring became recognised as a skilled craft (Efrat 1982, p. 3). Clothing techniques slowly developed into the practise we recognise as patternmaking. In the thirteenth century local craft guilds began to appear in England (Cooklin 1997, pp. 42 - 43). These guilds would maintain absolute control over the way clothing was made, and their dominance would not be shaken until industrialisation in the 18th Century (Cooklin 1997, pp. 42 - 43). This guild system would establish the convention on a master craftsmen working in a studio with apprentices. Clothing technology would progress to the point that in 14th century

France garments started to become more fitted (Chen 1998, ch. 2 p. 26). By the 15th Century patternmaking had become more extravagant with the invention of techniques such as "slashing". This effect involved cutting a slit in a fabric and pulling the lining through for decorative effect (Laver 2002, p. 78). Clothing clearly became more extravagant, while the styles used still resembled variations of medieval tailoring

Moves Towards Fitted Garments

The 18th Century saw great advances in patternmaking. According to Efrat (1982, p. 4) from the middle of the century there was increased interest in tight-fitting garments of elaborate design. This would require better-fitting garments and the techniques to construct them. According the fashion technologist Yu, in the late 18th century most clothing was custom-made by tailors who employed unique personal techniques for fitting clients (2004, p. 174). A general desire for more fitted clothing revealed the unreliable nature of their measurement and patternmaking methods. By this time the use of patterns were widely adopted by most tailors (Chen 1998, ch. 2 p. 26).

These events initiated the search for a system of tailoring which could reliably make elegant and fitted clothing. Fitted garments would require more accurate measurements and well-considered patternmaking techniques. From the 19th century the use of tape measures would be generally adopted by patternmakers (Efrat, 1982 p. 3). This was an era before systems of standard sizes and industrially-manufactured clothing. The introduction of machines and the industrialisation of the manufacturing process would naturally change all this.

According to the fashion technologist Bubonia, at the end of the 18th century new technologies such as the mechanical cotton gin, the spinning jenny and the power loom were able to do the work of many workers in a fraction of the time (2012, p. 4). Jobs that were given to entire communities of weavers were replaced with machines. Industrialisation would decrease the cost of manufacture and change the entire structure of clothing manufacture.

> "With the invention of the sewing machine around 1850, faster and more efficient ways of making mass-produced clothes were established and the need for sizing systems with clear communication was felt. Developments in sewing equipment, cutting and distribution, and also mass production methods, have facilitated ready-to-wear products."
> (Otieno, 2008 p. 76).

Industrialisation would indeed spread to the entire construction process, with fabric-spreading machines in the 1880s, buttonhole machines in the 1860s and the first steam presses in 1905 (Cooklin 1997, pp. 43 - 45).

Development of Ready To Wear Clothing

The impact of ready to wear clothing would expand in the 19th century with the industrialisation of the fashion industry. The patternmaker Hume remarks that "The making of clothing to standard sizes is not a new idea. In the seventeenth century tailors, in busy ports like Bristol, kept a stock of ready to wear clothing for those of their maritime customers who had not the time in port to wait for a finished garment." (Hume 1945, cited in Kunick 1984, p. 1). At this time, ready to wear would emerge out of necessity. The 19th century phenomenon of mass manufacture had increased efficiency and would allow clothing to be made in greater quantities for reduced cost - in fact leading to faster ways of producing and selling clothing.

Ready to wear clothing introduced new challenges for patternmakers. The size of a piece of clothing would have to be optimised to fit a wide range of people. This led manufacturers to establish a sizing system in order to differentiate their range of ready to wear clothing. Clothing would be designed to fit a range of people instead of single individuals, increasing the importance of surveys and measurement information to be gleaned from customers. Tailored garments had always been designed to the needs of a wearer through an iterative process of garment fitting. By contrast, ready to wear clothing would be expected to fit the customer first time and would not be re-fitted or altered by the manufacturer.

According the fashion patternmaker Kunick, the mid -19th century saw ready to wear clothing beginning to be sold in bulk quantities, and size notation became important to garment makers (1984, pp. 1-15). The need to create clothing that accurately fitted a range of people led to the rapid development of new patternmaking systems. Systematic garment pattern construction was clearly required to meet the demands of society and the clothing industry (Chen 1998, ch. 2 p. 26). Patternmaking that was less accurate and relied on the tailor re-fitting the garments to the wearer became less competitive in relation to ready to wear.

The Rise of Patternmaking Systems

The 1890s were prolific years in the development of patternmaking. “The origin of the art of cutting by system was unknown”, and “in the first quarter of the nineteenth century there was quite a concourse of authors and inventors of systems”(Giles 1896, cited in Chen 1998, ch. 2 p. 29). Increased interest in fitted garments was facilitated by the spread of tailoring trade publications. According to Kunick:

> “Women's measurements in the 1890s was a subject more controversial among the tailoring fraternity than it is today, and since it was not possible to conduct a true body measurement survey, authors devised proportionate measure systems based on their daily practice.” (1984, p. 3).

Tailoring techniques at the time were a hotly debated topic with each tailor justifying his or her own techniques using different principles. Although it was a time when patternmaking formulae and body measurement ratios were being developed, many of the conventions such as how and where to take measurements on the body were not yet established.

Patternmakers had the additional problem that it was not always socially acceptable to take measurements of the naked body. Many patternmakers would have to invent clever formulae to estimate measurements they could not accurately measure. Some tailors had little access to direct measurements of their customers due to the latters’ modesty (Kunick 1984, p. 3). Male tailors who could not obtain direct measurements for such reasons had to rely on an untrained female assistant to take measurement or even the customer taking “self-measurements” - which tended to be far from reliable.

This problem was compounded by the wearing of corsets, petticoats and dress improvers (or bustles). Patternmakers such as W.D.F. Vincent had patternmaking systems that omitted the need for a hip girth in their measurements as they were considered of no value (Kunick 1984, p. 1). The tailor James Thomson stated “I never take the hip measurement as I find it of little use owing to the 'Dress Improvers' that are now worn.” (Kunick 1984, p. 1). The wearing of corsets would also exaggerate the width of the bust and decrease the width of the back measurement (Kunick 1984, p. 2). This led to many diverse approaches to drafting patterns.

Divergent Approaches to Patternmaking Systems

During the aforementioned period, patternmaking systems grew in sophistication, and there were many divergent opinions on how to get the best fit. Each system would have a different approach, and ideas were often hotly debated by patternmakers. This confusion is best captured by the patternmaker Thornton:

> "Many complete books might be compiled on the divergent opinions entertained by cutters as to the correct outline of the standard model designed for a body garment. There is seldom a meeting of cutters for the discussion of technical problems, at which the novice is not perplexed by the confident yet conflicting declarations of presumably experienced men, upon points on which it might reasonably be conjectured that no difference of opinion could possibly exist." (1908, cited in Kunick 1984, p. 5).

Undoubtedly, these different contemporary approaches to patternmaking would have appeared more divergent than they are today. However, patternmaking systems can be devolved into different approaches that place different levels of emphasis on body measurements. Chen categorises the profusion of techniques developed from 1780 to 1950 into three strands: Proportionate, Direct and Sectional (1998, ch. 2 p. 28).

The Proportionate System

The Proportionate System is based on the notion that the human body conforms to an orderly set of body measurement ratios. Using one key measurement allows the rest of the body measurements to be extrapolated. For instance, the chest girth measurement is usually chosen as a control measure. The basis of these proportions can be anything from the tailor's rule of thumb experience to early measurements and surveys conducted with that tailor's customers. It must be assumed that these tailoring systems worked within the limitations of an individual's personal practise. According to Kunick (1984), by the end of the 19th century most tailors made up garments for both sexes. They took measurements over the clothed figure, and not from a body which required the removal of outer garments (Kunick 1984, pp. 4 - 5). This must surely have limited the reliability of measurements, a fact confirmed by the tailor Samuel Keyworth, who could never directly measure his female customers due to the modesty restrictions of the time (Kunick 1984, p. 3). Limited thus in his ability to measure a naked body, Keyworth resorted to conducting anatomical studies, delving into ancient history (Kunick 1984, p.3). He based his proportions on a commonly-held theory that the average man or women was "eight heads" in total height (Kunick 1984, p.3). From these ratios he could extrapolate the proportions of the rest of the body. This ratio may seem arbitrary, but according to Kunick "This theory is still widely held today, and forms the basis of many systems of pattern drafting." (1984, p. 3). Techniques such as "The Old Thirds System" took the wearer's chest girth and divided it into different ratios to draft the rest of the pattern (Chen 1998, ch. 2 p. 29). The Minister system introduced in 1820 introduced ideas such as drafting patterns in a square for balance and ease of methodical construction (Chen 1998, ch. 2 pp. 29 - 30), and Poole and Morris's systems introduced different ways of constructing patterns from chest and height measurements (Chen 1998, ch. 2 p. 30).

Introduction of the Tape Measure

Measurements are the key to all fashion construction. The "measurement taker" would be commonly used from medieval times until the 19th century (Waugh 1964, p. 34). This was merely a strip of paper or parchment on which measurements were recorded around the body and then translated onto the fabric. It was not until the mid-19th century that the tape measure gained prominence (Efrat 1982, p. 3). This was a revolutionary invention - a strip of material on which standardised measurements were placed. Measurements could now be recorded as figures instead of mere distances, and these figures could be manipulated and analysed. Measurements as numbers could be communicated at a much faster rate, and if a tailor had a tape measure he could reproduce patterns recorded as instructions and numbers on paper. This allowed patternmaking techniques to be documented onto paper and from there into trade publications. Tailors became generally familiar with taking measurements and drafting them directly onto fabric. While paper was rare or non-existent in earlier centuries, by the 19th century it was cheap and relatively abundant. Drafting patterns onto paper before committing them to fabric allowed patternmakers to experiment more widely with drafting without ruining the fabric. According to Efrat (1982, p. 4) the tape measure drew attention to the comparative relationships that exist between various parts of the body.

> "By realising that there is a relationship between breast measurement and length to waist, chest width, back and scye measurement, a new approach to the production of garments was introduced, whereby drafting systems were used, based on the application of geometric rules and principles to the anatomical proportions of the human figure. This was the breakthrough into the more sophisticated tailoring profession that is known to us today as the clothing industry." (Efrat 1982, pp. 4 - 5).

Here then was a critical discovery in the development of modern patternmaking techniques.

Introduction of Anthropometrics

Historically, one of the most outspoken patternmakers was Dr Wampen, whose patternmaking system was first published in 1837. Wampen was a mathematician who had been inspired by tailors, yet was extremely critical of the “plus and minus divisional systems”, a form of proportionate system common at the time (1903, p. 19). He refers to his own system as “bringing the new science of Anthropometrics to tailoring”. In essence this is the study of measuring the body and making surveys of body measurement, and to increase the accuracy of body measurements Wampen uses anatomical terms to identify “body landmarks”. Such measurements allowed Doctor Wampen to pride himself on deriving so-called “scientific” body-proportion ratios with greater accuracy. Further, he was critical of tailors who claimed to take accurate body measurements with the use of a tape measure. Wampen makes the observation:

> “Although measuring a customer appears, and is, a very simple process, it has the paradoxical element of it being almost impossible to take a measure that is indisputably correct, because of its being ever subservient to the will, fancy, or judgment of the measurer and the advice of the customer, and therefore is productive of the most varying results.” (1903, p. 42).

According to this system, the patternmaker is to begin by drafting a standard-size pattern derived from Wampen’s anthropometric studies. Wampen’s measurements are to be accompanied by notation for any irregularity in the body form. Meanwhile, his description of pattern construction is extremely methodical, even to the extent that Chen remarks that Wampen’s work was too difficult for tailors to understand and that he used far too many technical terms (1998, ch. 2 p. 31). Despite having access to “anthropometric” studies, the body proportion ratios to be derived would still be limited in their accuracy. Chen suggests (1998, ch. 2 p. 31) that proportionate systems have lost popularity over time, due to the fact that systems that using formulae for body proportions tend to lose accuracy as the ideal body figure changes over time.

Direct Systems

Direct systems are generally based on drafting flat patterns entirely from body measurements. Hearn's patternmaking system of 1823 is seen as the founder of the direct measurement system (Giles 1896, cited in Chen 1998, ch. 2 p. 33). This system is similar to many modern patternmaking techniques. Direct measurements can be problematic because the measurements themselves can be extremely variable. Efrat states that:

> "This method, however, is fraught with inaccuracies and places too much responsibility on the tape measure. The tape measure in the hand of any but the more experienced craftsman, can be very unreliable." (1982, p. 10).

Even if the patternmaker is trained to recognise body landmarks and making accurate measurements, there is no guarantee that the final measurements will create a fitted pattern. Tape measurements tend to lose accuracy around such curved parts of the body as the hips and bust. Chen describes how these systems are criticised because the method of taking measurements is more determined by the accuracy of the garment construction that the system itself (1998 ch. 2 p. 33). As a result, the variable accuracy of direct systems led to the development of other techniques that were more practical for patternmakers.

A Shift In Undergarment Construction

By the 1920s there was a shift away from highly-constructed forms of fashion such as bustles and corsets. These were replaced by body-fitting styles with easier range of movement. Stiff corsets made way for new softer-fitting bra constructions. All of this dramatically changed the silhouette of the female form. Kunick describes a phenomenon in the 1920s where the average hip girth of a woman was 4 inches larger than her bust (1984, p. 8). Within a single generation this measurement changed from 4 inches difference to 2 inches, in a single generation of clothing. "This was caused by a change in bra design and reduced constriction at the waist." (Kunick 1984, p. 8). At this time bra construction was still quite primitive and was only capable of creating shapes that concealed the bust rather than exaggerating its shape. Kunick describes how "industrial production lacked the expertise for producing shapely garments" (1984 p. 8). In Europe this led to a trend in bras that concealed the bust to give a boyish look. This "long, lean" look both adopts the new bra technology and uses a less restrictive waistline. Dresses such as the "Charleston dress" with its long loose bodice, typify this look.

Sectional Measure systems

The shifting ideal of body forms in the 1920s, allied to new forms of undergarments, would affect patternmaking systems. Body measurements were always taken with women wearing undergarments. True, new undergarments would create new silhouettes and shatter many of the pre-existing assumptions for proportionate body measurement ratios, yet the use of key measurements such as bust, waist and hips still had limited accuracy in creating well-fitted patterns. This led to patternmakers needing to take additional measurements as well as figure out practical ways to capture the human body. Breaking the body down into different sections and taking more measurements allowed the accuracy of these patterns to be increased. This method embraced the idea that different parts of the body would vary in differing proportions. Hopkins describes how the addition of supplementary measurements such as the width of the shoulders is essential for constructing closer-fitting garments (1990, pp. 3 – 4, cited in Chen 1998, ch. 2 p. 35). He observes that "the sizes of the shoulders vary in proportion to the breast measurement" (Hopkins 1990, pp. 3 - 4, cited in Chen 1998, ch. 2 p. 35).

The introduction of bras and closely-fitting clothing led to an increase in the importance of measurements. Bras that suppressed the bust would in fact change body-proportion ratios. Similarly, the hip measurement that was previously ignored in honour of bustles now became a key measuring component for fitted garments. Kunick describes how:

> "the hip girth is a better predictor of other body measurements than the bust, partly because the bust is not an easy measurement to take with accuracy, and because the size of the bust can so easily be altered by a change in foundation garments." (1984, p. 8).

In sum, we see that styles of patternmaking that rely on taking more and more supplementary measurements are similar to our modern patternmaking systems.

Men's and Women's wear

It is a truism that men and women have fundamentally different body shapes. In ancient times when clothing construction was as simple as draping cloth over the body, there was less differentiation between the sexes. When over time clothing became more fitted, different cultures created conventions for men and women. Clothing that distinguished the sexes became more stylised and required greater expertise, and over time men's and women's clothing found different ways to express the concept of extravagance. For instance, in Europe the shift from corsets to bras in the 1850s gave women's clothing greater freedom of movement. Similarly, the introduction of the woman's suit by John Redfern in the late 1860s gave women further mobility (Bigelow 1985, pp. 242 - 245; La Haye 1996, p. 39, cited in Chen 1984, ch. 2 p. 26). The woman's suit was derived from techniques used in men's tailoring (Thornton & Moulton 1949, p.15; Bigelow 1985, p. 242, cited in Chen 1998, ch. 2 p. 27), and this specialisation of tailoring between the sexes would establish many of the conventions for men's and women's wear that are part of the modern fashion system. Indeed, women's wear would continue to be affected by style innovation and the appreciation of fit, whereas men's garments have not changed very much during a century (Chen 1998, ch. 2 p. 26 - 27).

Origins of Block Patterns

As patternmaking evolved according to the needs of mass manufacture, block patterns emerged as an efficient way of generating patterns to fit an individual's measurements. These are patterns in the shape of a common garment such as a coat, skirt or trouser. Using body measurements the patternmaker can draft a block pattern to fit an individual. The pattern can also be manipulated into different designs while maintaining the fit of the original garment. Holding describes a block pattern:

> "A block pattern is a base from which you can deviate into any style you like. A block pattern is really a Frock coat, clerical waistcoat, or trousers pattern." (Holding 1905, p. 9, cited in Chen 1998, ch. 2 p. 28).

Hopkins describes how:

> "A good set of block patterns is, then, a valuable possession amongst a cutter's set of tools. These should consist of a set of jackets, one of bodices and one of vests, cut in the single-breast style." (1990, p. 4 cited in Chen 1998, ch. 2 p. 28).

It is significant that the earliest users of block patterns knew of some of the limitations of such as system. Holding describes how:

> "It is important in connection with these patterns to recollect that they are not cut for any excessive drawing in, stretching or manipulation, and certainly they are not cut for big shoulder pads or stiffened fronts." (1905, p. 9, cited in Chen 1998, ch. 2 p. 28)

Such block patterns had the limitation that they would start to lose accuracy when using shoulder pads and stiffening, which are the cornerstones of the tailored suit. Clearly, the manipulation of patterns and their interaction with different clothing-construction techniques would continue to be a challenge for patternmakers over time.

Paper Patterns

The first patterns were documented on slate in the 12th century (Thornton & Moulton 1949, p.12, cited in Chen 1998, ch. 2 p. 26). At this time paper was incredibly rare and unavailable to most people. By the 19th century, paper was inexpensive and became an efficient medium for recording and sharing garment patterns. At the beginning of the century shops in London started to sell paper patterns of garments, which were sold to professionals rather than to home dressmakers (Arnold 1973, p. 121, cited in Chen 1998, ch. 2 p. 27). During the nineteenth century, different systems of garment pattern cutting continued to be published (Davis 1994, p. 1 cited in Chen 1998, ch. 2 p. 27). In the second half of the century home dress making became popular (Chen 1998, ch. 2 p. 27), and the invention of the first commercial sewing machines from the 1830s and the 1850s (Burns & Bryant 2007, p 6.), would empower the home dressmaker. Paper patterns were designed and sold to these home dressmakers, developed by companies such as Butterick, McCalls's Vogue, Simplicity and Burda (Chen 1998, ch. 2 p. 27). Further, from the 1880s patternmaking schools appeared (Arnold 1973, pp. 3; 121 – 126, cited in Chen 1998, ch. 2 p. 27). Paper and cardboard would certainly remain essential materials in the garment-making process.

Drape

Drape is a form of clothing construction that has existed since the invention of clothing. Indeed, it was commonplace in ancient civilizations such as Greece and Rome (Laver 2002, p. 7). Drape is to be seen as an essential part of clothing construction, long used to fit clothing to the body, and throughout history it has mirrored the development of patternmaking. Drape as a crafting process has always been heavily dependent on the skill of the draper. In the 20th century, draping was elevated to new levels of sophistication when Madeleine Vionnet developed new bias-cutting techniques (Bubonia 2012, pp. 239 – 240). Her techniques utilised the unique flexible properties of fabric when it is draped on the bias, that is, diagonal to the grain of the fabric.

Draping invariably requires fabric to be manipulated with the hands, while making careful judgements. Fashion technologists Fan *et al.* describe drape as a complex combination of fabric, mechanical and optical properties (2004 p. 114). These are assessed subjectively by the tailor and wearer. Drape has a physical component, which is always enhanced by the hands-on experience of the draper. Creating draped garments is considerably more intensive in terms of time, material and labour than other patternmaking processes. There exists draping literature which systematises the practice into a series of steps and procedures. We observe that some practitioners are very methodical when they drape while others consider it a free-form crafting process.

While draping is sometimes regarded as a different form of garment construction to flat patternmaking, these disciplines overlap. In short, skilled flat patternmakers need to know how to drape garments. Drapers in turn need to use the same skills as patternmakers to convert their designs into flat patterns for garment construction. There is no doubt that a skilled maker of clothing should be able to drape garments as well as make flat patterns, and drape and patternmaking have evolved over time as two sides of the same coin to the extent that drape is an essential and inseparable part of patternmaking.

Establishment of a fashion hierarchy

The development of the couture house as a brand-new business model, marked a great shift in the fashion industry. The first couture house was established by Charles Worth in 1860 (Chen 1998, ch. 2 p. 27). Designers who were previously subservient to their patrons began to present new collections to their clients each season, allowing the designer for the first time to dictate styles and fashion to patrons. In turn, the novelty and creative freedom of couture increased the speed at which new fashions were released. “Haute Couture” came to be seen as the highest form of fashion and, crucially, established a fashion hierarchy.

This hierarchy divided fashion into the different streams of clothing we are familiar with today, namely: couture, ready to wear, and mass market clothing. Each stream specialises in its approach to patternmaking. Couture would always focus on custom-fitting clothing, and would focus on using the best teams of craftsmen and latest technology in the creation process. Mass market and ready to wear would in their turn need to establish a system of sizes, relying on body measurements and the surveying of customers. Each level of fashion would establish its own conventions, business models, techniques and quality-expectations from its respective customers.

Development of the sizing system

The development of sizing systems became necessary with the emergence of ready to wear clothing. The fashion technologist Winks states:

> “Ever since garments were first mass-produced as 'readymades', the problems of what sizes to make, and the lesser problem of how to label them, have existed. Each branch of the ready-made garment industry or 'confection' industry as it is called in European countries has, from its beginnings, required to establish some system of size grading and of size marking for its products before entering into bulk production.” (1997, p. 1).

Many of these practises grew out of basic necessity. “French clothing manufacturers in the 1860s started accumulating measurement data and over many years of production started making papier mache stands to individual measurements” (Cooklin 1990, p. 4). The French in fact adopted a size interval that became the basis of most European size systems used today. These stands constituted some of the first mannequins, establishing the concept of garment sizes. Each manufacturer would develop their own system of sizing, which ended up being as diverse as the range of clothing manufacturers. The establishment of such sizing systems in the 20th century would lead to many countries independently developing their own surveys and employing different sizing standards (Yu 2004, pp. 174 - 177).

20th Century tailoring

The Great War beginning in 1914 had a huge impact on the clothing industry. The war ushered in the need for mass-manufactured uniforms for the military. It also engendered a scarcity of materials for the civilian population. This in turn forced the clothing industry to become much more efficient. Meanwhile, many skilled members of the clothing industry would be recruited to fight in the war. According to Efrat this created an absence in skilled labour (Efrat 1982, p. 5). In response, production engineers from other industries were employed to make production more efficient. In a "clothing production line" garment construction was required to be achieved in the shortest possible time while maintaining manufacturing standards:

> "To achieve this, 'production lines' were introduced whereby all the manufacturing operations previously carried out by the tailor, were now performed by a number of machine operations" (Efrat 1982, p. 5).

In sum, this would change the process of patternmaking. Complex tasks which were performed by tailors were re-examined and deconstructed so that they could be within the reach of unskilled workers. Tailors previously had had time to re-fit and adjust garments to fit the body. The introduction of:

> "mass production methods meant that it was absolutely essential for there to be no alterations or reshaping of garment parts subsequent to the cut garment leaving the cutting room" (Efrat 1982, p. 5).

Garments were expected to fit the wearer as soon as they came off the production line. Consequently, garment styles tended to be simple and easier to mass-produce. The development of the production line would profoundly shape the fashion industry. Once a cottage industry where workers would create in their own homes, mass-produced fashion would now assemble tailors under a single roof. Working on an industrial scale would in turn create the need for manufacturers to find more efficient and reliable ways of making clothing. "By the end of World War I, clothing manufacturers realised that more rational methods of pattern construction and grading were required" (Cooklin 1990, p.5). According to Yu (2004, p. 174) by the 1920s the demand for mass-produced clothing created the need for a standard sizing system. By the 1930s, mail-order houses became popular. Due in turn to the frequent returns of ill-fitting garments, new ways were sought out to create better-fitting garments. This led to the first anthropometric studies, carried out to determine a sizing system for women's apparel (Yu 2004, p. 174).

Modern Anthropometric Surveys

Anthropometrics, the study of body measurements, became increasingly important in 20th century fashion. "Anthropometrics can be defined as the science concerned with the measurement of man." (Yu 2004, p. 169). According to the fashion technologist Winks, inquisitive minds from Hippocrates to Da Vinci have tried to classify the body into different archetypes (1997, p. 7). Body measurements have been used in everything from developing more realistic anatomy in artwork to making discoveries in the medical industry. Modern anthropometrics offered more accurate measurements using the tape measure and rule. As stated earlier, anthropometrics in tailoring was introduced by tailors like Dr Wampen in 1837 (Chen 1998, ch. 2 p. 26) and Samuel Keyworth (Wampen 1903, p. 15). Publications such as "Anthropometrie" by Quetelet in 1870 typify this area of research (Winks 1997, p. 7). Here was a scientific study of body measurements with records of measurements of different body sizes and shapes. The combined knowledge of anatomy and ability to identify body landmarks led overall to more accurate measurements. Yu describes how:

> "Landmarks are located by anatomical points and grouped according to their positions on the body. This provides a predetermined order to permit greater speed in body measuring" (2004, p. 169).

Doubtless, the role of body measurement surveys would have powerful applications in the fashion industry. Early studies conducted by clothing manufacturers were of a relatively small scale. According to Chen "In the second quarter of the twentieth century, sizing information was used increasingly to systemise garment construction" (1998, ch.2 p. 15). The size and significance of the data acquired in surveys increased. The first published clothing surveys conducted in the USA in 1921, measured 100,000 men (Winks 1997, cited in Otieno 2008, p. 77). Similarly, the first major women's clothing surveys, measuring 15,000 individuals, were taken in the USA from 1939 to 1940 (O'Brien & Shelton 1941, cited in Otieno 2008, p. 77). Data from these surveys became the basis for the development of size charts in the USA, Europe and other parts of the world. Since the 1930s, anthropometric surveys have been used to collate data on military and civilian populations of men, women and children (Bye *et al.* 2006, cited in Otieno 2008, p. 77). The first scientific large-scale body surveys for women's wear garment sizing were held in the USA in 1941, United Kingdom in 1951, France in 1968 and West Germany in 1970 (Kunick 1984, pp. 8 – 12; Cooklin 1990, p. 9, cited in Chen 1998, ch. 2 p. 15).

Ready to wear clothing at the same time became prominent, and the need for body surveys to establish a sizing system became of great importance. Surveys themselves form a historical benchmark for industry standards (Otieno 2008, p. 71). Meanwhile, modern anthropometrics would evolve to use sophisticated measuring devices such as: measuring tapes, callipers, adapted tape measures and anthropometers. Later on, these technologies would evolve into processes such as "somatography" (a process of photographing a body's silhouette), body form casting and three-dimensional computer scanning.

Development of modern sizing systems

As clothing shifted from being custom-made in the latter 18th century to mass-manufactured in the early 20th, there was an obvious need for sizing systems (Yu 2004, p. 174). Early sizing systems were unique, devised by individual manufacturers who would produce garments at different sizes based on observations or size information gained from their customers. By the 1920s the demand for mass-produced garments created the need for a standard sizing system, replacing the situation where a tailor's skill would determine the success of their business and the accuracy of their clothing. The efficiency of a business, clothing manufacture and the ability to fit the customer now relied on making decisions about the sizing system. Yu (2004, p. 185) describes how sizing systems are created by choosing a range of population and dividing them into different body types based on dimensions such as height or body ratio. Size categories are then developed into a range of sizes.

As anthropometric surveys became available to garment manufacturers it became possible to analyse larger segments of the population, and the manufacturer could now create a strategy to fit a population-range. These choices would determine the different sizes they intended to create. This introduced the concepts of "sizing intervals" and "grading". A patternmaker would create a garment from measurements in the middle of the size range. The pattern of this garment could then be scaled up or down in different ratios to create different sizes. Scaling the patterns into different sizes became the technique of "grading". The different sizes and their proportions became the "size interval". All this amounted to the sizes produced by a garment manufacturer becoming increasingly important over time:

> "Size classification is the main element which enables the garment industry to develop garments with efficiency and accuracy. It is a guide for consistency in sizing for bulk production, and is required for factors such as styling, pattern designing, fabric quantities and making-up." (Kunick 1984, p. 12).

Over time more surveys were conducted, with efforts being made to systematize the data. In the United Kingdom sizing codes were established that would represent garments with standard measurements, wherein a code contains a set of net body measurements for garment construction (Chen 1998, ch. 2 p.15). Size charts have also become an important standard in clothing. According to fashion technologist Croney (1980, cited in Otieno 2008, pp. 82 - 83) they are used for standardisation, garment labelling, stock management and size identification for the consumer. Manufacturers also use sizes for storing their own proprietary information and as a marketing tool for consumers.

Efforts to create international clothing standards and sizing increased, but it was not until 1968 that the International Organisation for Standardisation was set up in Sweden with the aim of creating international clothing standards (Yu 2004, p. 182). The increased size and accuracy of anthropometric surveys should have improved garment fit, but it did not solve all the associated problems. Instead of a global system of sizes over the 20th century, many countries independently developed their own surveys and employed their own sizing standards Yu (2004, pp. 174 - 177). Moreover, the size codes themselves all used different standards and proved more of a guide than empirical standard. For example, the size code in the United Kingdom is a size "code", not an exact "size". This means that while it is not the exact size, it is nearer to that particular size that any other (Kunick 1984, p. 12). Each individual manufacturer creates a set of sizes to fit a range of the population, whereby these sizes are relative to each other but do not really follow any sort of universal standard:

> "Size labelling is a tool for assisting consumers to choose apparel that fits their body properly. However, garments sizes are indicated by arbitrary numbers which may represent different key measurements in different systems." (Yu 2004, p. 188).

In summary, we clearly see that anthropometrics and sizing systems, while helping to fit garments to a wide range of the population, yet reveal limits to their accuracy.

Introduction of synthetic materials

The introduction of new synthetic materials in the 20th century would have a dramatic effect on the fashion industry, beginning with the introduction of artificial silk made from cellulose in 1891 (Burns & Bryant 2007, p. 90). The ability to manufacture materials from synthetic sources was typified by the introduction of nylon in 1939 (Laver 2002, p. 254). Synthetic fibres possessed new mechanical and tensile properties. The rise of textile technologies accompanied by developments in plastics and adhesives would change garment construction. New fabrics with stretch properties were much more flexible than traditional materials made from natural fibres. The 20th century would see the introduction of synthetic fibres such as acetate, acrylic, polyester and spandex (Bubonia 2012, p. 5).

Such a new generation of materials would mean that the garment pattern did not need to be so exact. Patterns for garments such as the t-shirt rely more on the flexible properties of the material than the shape of the pattern to maintain a fitted garment. Stretch materials are increasingly being used in clothing applications such as fashion, sportswear, medical, intimate body wear and technical garments (Watkins 2011, p. 262). In terms of ready to wear clothing, this would shift the emphasis away from the skill of the patternmaking towards the properties of the materials in fashioning better-fitting garments. However, flexible materials cannot replace all materials and do not always achieve the comfort or aesthetic appearance of tailored clothing. There is indeed still a great need for fitted clothing patterns.

The Modern Fashion System

The modern fashion system has developed under the influence of new technologies, new materials and new business models. Clothing construction is divided between quickly producing accurately-fitting garments and artfully crafting custom-fitted garments. Custom-made clothing has become increasingly rare, with ready to wear and mass-market clothing dominating. Custom-made clothing is seen as the height of fashion design due to its expensive, rare and skilled construction techniques.

There are three traditional methods for generating patterns: drafting basic block patterns from body measurements, modifying a pre-existing block pattern into different designs, and draping fabric on a mannequin or model (Watkins 2011, p. 246). Chen describes "the principal method of creating patterns in the mass clothing industry is by the adaptation of blocks which are mathematically constructed" (1998, ch. 2 p. 3). In modern times:

> "3D manual pattern cutting is usually practised by bespoke and creative designers modelling the style directly on the garment stand. This technique is sometimes used in industry to solve

particular problems. It is often preferred but it is more time consuming and individualistic, and therefore less controllable." (Chen 1998, ch. 2 p. 3).

The Modern Patternmaking System

The modern fashion system has become a slick and efficient manufacturing process. Each part of the production process has developed into specialised roles that are primed for manufacturing efficiency. Ready to wear embraces the idea of sizes, so that designers created a standard-size garment which could then be graded into different sizes. The fashion block pattern in turn evolved into a sophisticated system of "manipulations". To shape clothing, triangular or rectangular wedges are sewn out of flat fabric to give the clothing a three-dimensional shape. These are called "darts" and are used to shape fabric about the body. Patternmakers in essence developed techniques where block patterns could be manipulated. The "darts" and seam lines they created could be moved around the garment while maintaining approximately the same sized garment. This allows designers to rapidly create many variations of a single block.

Designers can also modify a block pattern to create different effects. By adding "fullness" to a pattern they can alter it to become more voluminous. "Contour" tailoring is a way of creating curved garments that fit closely to the body, so that manipulating contours becomes a highly skilled process. The practise of draping a garment on a mannequin or a model has also evolved. A multiplicity of techniques were meanwhile initiated to describe the draping process. Modern drape has also developed processes such as "truing" to increase the ease of production. This involves flattening the draped patterns and re-drawing the lines of the patterns so that they are smoother and easier to manipulate, giving them a form which is similar to a block pattern and allowing them to be manipulated using flat patternmaking techniques. However, the entire drape process is still heavily reliant on the patternmaker's skill and experience.

Modern strategies to achieve the Ultimate Fit

Modern fashion has evolved into an industry with a multiplicity of business models and manufacturing strategies. Chen remarks: "It is generally understood by the cutters that there is no system which can be used as a standard system for all the garment construction." (1998, ch. 2 p. 35). There are nowadays multiple strategies on how to accurately fit garments to the body. The notion of fit has been broken into numerous different approaches with their own objectives. Many of these approaches assume that technology, resources and human skill will be able to find an adequate fit for the garment. Yet some of them are so expensive that the average consumer will never be able to experience them. Meanwhile, other approaches are so ubiquitous that consumers barely even notice them.

The following is a survey of strategies.

Couture and Bespoke Tailoring

The separation of the market into couture, ready to wear and mass market clothing has allowed the high end of the market to provide its own solutions to fitting. Bespoke tailoring and couture offer a service where constant alterations ensure clothing will fit. Teams of highly-trained tailors and patternmakers craft clothing to fit the individual, whereby it is assumed that the collective skill of the team will be able to solve any fitting problem. This work is exquisite; the only downside is that the cost of garments is astronomical. In couture, an evening gown can cost upwards of $15,000 (Shaeffer 2007, p. 8). Such luxury clothing can only be purchased by a coterie of extremely wealthy individuals.

Couture houses or bespoke tailors undoubtedly retain barriers to entry, whereby most will only sell their garments to specially-invited clients.

Skilled Tailors and Alterations

Not all custom clothing must be bespoke or couture; the world is replete with skilled tailors. In countries with high labour costs such as the United Kingdom or United States only the elite can afford custom clothing, whereas in places where labour is inexpensive such as China or India custom clothes are more affordable. If the wearer changes body-shape over time he or she can readily have garments altered. In theory almost any garment can be constantly altered, but in practise it is a different proposition. Modern mass production allows garments to be manufactured at a comparatively low cost compared to a custom-made garment, yet such mass-manufactured garments are constructed using techniques that do not favour alterations. For example, seam allowances in a mass manufactured garment are cut to the minimum since the garment is not designed to be altered. A tailored suit by contrast will offer slightly longer seam allowances so that the garment can be altered if the need ever arises. To make alterations at today's labour costs often incurs a high percentage of the garment cost, at times even more expensive than the purchase price. This means consumers will often choose to purchase new garments before altering existing ones. On the other hand, in countries where labour costs are relatively low, alterations and custom-made clothing are an affordable option.

Stretch Materials

The introduction of synthetic materials and stretch materials give new options to patternmakers. Many fashion designers assume that these "hi-tech" materials will solve all the fitting problems of the future. Patternmaking for stretch garments introduces new concepts such as "negative ease" whereby a garment is designed anticipating the size it will stretch into. This is a specialised area, and designers often overlook new fitting problems that stretch garments bring. Like any patternmaking art form there is a craft to it. Hi-tech materials can fit to a body, but betimes will fail to do so in comfortable or aesthetically-pleasing ways. Likewise, many of these garments are stuck in a particular aesthetic, incompatible with certain social situations. Wearing a skin-tight athletic suit may be comfortable, but it may not be acceptable to wear it to a meeting where everyone else is in a business suit. Garments with stretch materials may solve many traditional fitting problems, but surely cannot resolve all of them.

Null Fitting and Anti Fitting Clothing

Some solutions involve altering the aesthetics of the clothing to fit the garments in other ways. A culturally-specific garment such as a poncho is not fitted and can fit almost anybody. This may be a solution for some problems, but the limited structure of these kinds of garments tends to dictate their aesthetic. More sophisticated versions of such garments include Issey Miyake's *Pleats Please* collections. These clothes are pleated and heat-set which give them flexible properties, allowing them to stretch and fit a range of sizes (Miyake 2012, pp. 34 - 39). The pleating of this textile does tend to dictate the aesthetics of the garment. Anti-fitting clothing attempts to create clothing that intentionally does not fit the body. While this may be poetic for an avant-garde fashion collection, it may not be an applicable or cost effective solution for all mass market clothing.

Better Anthropometric Measurements

Modern anthropometrics studies have burgeoned in size and accuracy, and their data is used by large fashion companies to generate their sizes. This is extremely important for mass-manufactured garments, and there is the hope that better measurement data and cleverer manufacturing strategies can fit the population more effectively. The introduction of three-dimensional scanners to take measurements should increase the accuracy of measurements (Yu 2004, pp. 177 – 182). However, anthropometrics are still heavily reliant on linear measurements, limiting their accuracy. Another problem with mass-manufactured patterns is that in trying to fit a wide range of the population, the design may not fit any individual particularly well.

3D Scanners and Computer Aided Design

The invention of three-dimensional (3D) scanners has created new opportunities in fashion patternmaking. "Since 1951, new measuring and sizing techniques and technologies have again led garment pattern cutting into another new era" (Chen 1998, ch. 2 p. 35). Prior to our familiar modern 3D scanners, techniques for measuring body shapes in 3D included: the sliding gauge, algin and gypsum body moulds, infrared and laser scanners (Yu 2004, pp. 137 - 138). The development of 3D scanning technologies allowed the body to be recorded as a "cloud" of points representing the shape of the body. Instead of taking several linear measurements the three-dimensional scan could take a theoretically unlimited number of measurements. Three-dimensional computer software has made it possible for the designer to virtually manipulate patterns. This common goal of advancing the accuracy of patternmaking remains a rapidly-growing area of research.

Smart Textiles

New technologies such as shape memory alloys, shape memory polymers and electro-active polymers are seen by futurists as a possible panacea for all our fitting problems. However, many of these are still at a theoretical or early stage of development. The researcher has explored smart materials since 2005 during his Master in Textiles Futures degree and has experienced many practical problems with bringing smart textiles into fashion. Researchers such as Joanna Berzowska (Berzowska & Coelho 2005) and fashion designer Hussein Chalayan have used shape memory fabric to create theatrical garments (Quinn 2002, p.27). However it is difficult to incorporate this new technology into fitted tailoring or anything that can be laundered. Current memory alloys such as "nitanol" require high amounts of heat and energy to activate. They are moreover incredibly expensive and not practical for mass production. There are also new considerations such as where and how to store a power source for the textiles, or how to insulate the memory wire so that it does not burn the wearer. There are many technical considerations which must be resolved before smart textiles become a viable option for the fashion designer. Even if a cheap and reliable form of memory polymer exists, there is little patternmaking research that considers how to make patterns for garments that are continually changing in shape, or how a garment would intelligently adapt to the shape of the body. This is a distant technology, in its infancy when it comes to application to fashion.

Just as techniques were invented in the past, it will be possible to improve them in the future. Throughout history the makers of clothing have constantly adapted to new technology and ideas. They have always struggled to create the best clothing possible according to the technology of the time. The search for new ways of creating clothing has engendered numerous different approaches. The patternmaker's ability to understanding the potential of new technology often leads to major innovations in fashion design. There have always been, and will continue to be, pioneers willing to seek out the next great advance in fashion technology.

CHAPTER 2

Fashion And Its Limits

Limitations of existing fashion patternmaking techniques

This chapter discusses the limitations of existing patternmaking systems and practises. It investigates the systemic problems encountered within fashion patternmaking. Common techniques and practises which may seem unremarkable to initial perceptions will be revealed to be more complex than previously imagined. A greater understanding of patternmaking has the potential to improve patternmaking systems and offer applications for emerging technologies.

In the 21st century fashion technologists have become the predominant technical experts in specialised fields of fashion. Fashion technologists are experts in specialised areas such as patternmaking, textiles, science and engineering. It is these technical experts who understand the weaknesses in existing patternmaking systems. Expertise in each area is highly specialised, and modern fashion production is compartmentalised into specialised roles. This has made communicating specialised technical problems between the different roles increasingly challenging.

The process of accurately fitting clothing to the human body is undoubtedly more complex than is commonly perceived. Fashion technologists themselves view clothing construction as a multidisciplinary process. The fashion technologists Renbourn and Rees consider the:

> "Science of clothing is to be regarded as an integration of the disciplines of the textiles and materials technologist, the textiles and materials biophysicist, the clothing physiologist and

> hygienist, the master tailor, the clothing and footwear designer, and the fashion student and artist in the widest sense. As such, clothing science represents an important aspect of man's cultural activity, a link between the technical and biological sciences and the social humanities." (1972, p. 249 cited in Watkins 1995, p. xviii)

In short, the science of clothing involves a diverse range of disciplines, from the sciences to the fine arts.

This thesis has already amply demonstrated that patternmakers use vastly diverging techniques and approaches to fitting garments to the human body. Yet there is no universal consensus over which techniques are the most efficient. Many techniques diverge on the most fundamental of principles. This chapter will analyse the limitations on key assumptions patternmaking systems are built on. It will address the limitations of the measuring and drafting techniques they use. It investigates the reliance on intuition and the judgement of the patternmaker. It examines the limitations of the definition of fit and the limited ability of patterns to adapt to body movement. It observes techniques that try to bypass the need for fitted patterns, such as anti-fit and garments with stretch materials. Finally, it explores how existing patternmaking methodologies limit the development of new technologies.

Patternmakers disagree over patternmaking practices

Patternmaking systems demonstrate conflicting views on how best to fit garments to the body. Thornton states that patternmakers have divergent opinions on the most fundamental principles of patternmaking (Thornton 1908, cited in Kunick 1984, p. 5). Patternmakers use different drafting formulae and put emphasis on different body measurements. Although patternmaking systems may be different they also have things in common. Chen conducted a comparative analysis of six prominently used patternmaking systems (1998, ch. 2 p. 40). These systems are all different yet their patterns resemble a common form (see figure 1), so that differing patternmaking systems are in the end diverse ways of achieving a similar result.

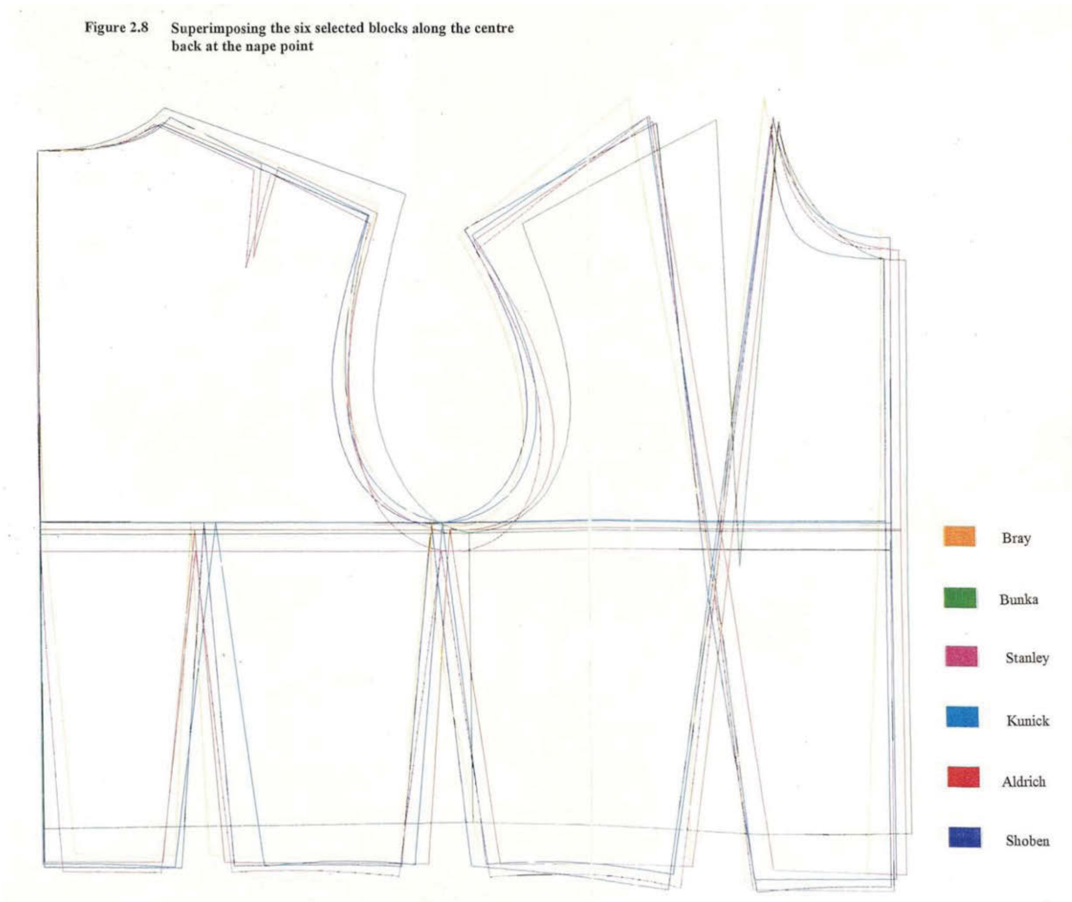


Figure 1: Chen compares six prominent fashion patternmaking systems showing they have similar forms (Chen 1998, ch. 2 p. 40).

Analysing different patternmaking techniques is problematic for the reason that while patternmakers often describe their process, few will attempt to explain the underlying principles of how their process works. The fashion academic Newton describes how:

> "…during the last hundred years, it emerges that the majority of publications discuss, debate and illustrate methods and systems of pattern construction. It is the exception for any reference to be made to the general principles of pattern construction."
>
> (Newton 1986, cited in Chen 1998, ch. 2 p. 36).

In short, we may understand that patternmaking systems are seen as sets of guidelines solely linked to the patternmaker who uses them.

The best systems are approximations and guides

Many patternmaking practitioners regard patternmaking systems as no more than a set of guidelines to aid the patternmaker. This places the responsibility of an accurate fit on the skill and judgement of the patternmaker instead of the patternmaking system itself. Whife states that:

> "However many measures a cutter may take and however carefully they may be applied to his draft, they will not of themselves give him a guarantee that all the garments he cuts by them will be perfect in fit" (Whife 1965, pp. 1 - 4).

Whife continues to describe how the observations and judgements of patternmakers are real skills and have to be applied in order to achieve a good fit, namely, that the patternmaker plays a critical role in the use of these techniques.

Patternmaking systems are based on translating body measurements into flat patterns. Different systems make different assumptions on how to draft a flat pattern. Watkins states:

> "All drafting systems to a greater or lesser extent make assumptions about the body shape based on derived measurements. It is the shape proportion and posture of a person that is important, but replicating the three-dimensional body shape in a two-dimensional pattern profile can be problematic" (2011, p. 248).

The difficulty of translating a three-dimensional form into a flat pattern is a problem common to all patternmaking systems.

Patternmakers accept the inherent inaccuracy of taking linear measurements and the need for trial-and-error fittings to achieve a well-fitted garment. Kwong is critical of the limited accuracy of body measurements (2004). He states:

> "The imprecise nature of taking linear body measurements with a tape measure and then applying such measurements for pattern drafting is evidenced by the need for repeated trials and fittings of the garment by a skilled technician after the pattern has been cut from cloth. Experience has shown that these linear body measurements are not directly applicable to pattern dimensions and are useful primarily as approximations" (Kwong 2004, p. 205).

We may clearly see that patternmakers have a limited ability to translate linear body measurements into accurate body measurements without multiple fittings. Watkins is critical of ready to wear clothing and remarks that "Despite the mass of supporting anthropometric data, traditional manufacture still relies upon measurements that have emerged through trial and error" (2011, p. 247). Treating patternmaking systems as a set of guidelines or "rule of thumb" has often distracted from the deficiencies within a patternmaking system.

There is also very little consensus between patternmakers on which body measurements are the most important when fitting the body. Different patternmakers place emphasis on diverse body parts. While hip and bust measurements are the two main control dimensions used in size codes used to identify the female body (Chen 1998, ch. 2 p. 9), not all patternmakers agree that these are the most important. Kunick (1984, p. 19) places emphasis on the hip measurement, while Chen argues that shaping the waist is the most critical (1998, ch. 2 p. 12). Winks (1997, p. 5) advocates the primacy of the bust measurement, while Hutchinson states how the critical role of the shoulder measurement is often overlooked (Efrat 1982, p. 36). Meanwhile, Efrat believes that fitting the whole body matters most (1982, p. 42). Each of these experts makes a strong case for the significance of fitting each body part, yet there is still a diversity of opinions on which body measurements best determine well-fitted patterns.

Limitations of "science" in traditional fashion patternmaking

There are traditional patternmaking techniques which claim to be accurate because they are based on scientific methods. Reviewing literature from different 19th and 20th century patternmakers, we find terms such as "scientific", "geometric" or "mathematical" to describe their work (Kunick 1984, p. 5). A good example is the patternmaker Dr Wampen, who made great claims about the scientific nature of his patternmaking techniques. He was certainly an early adopter of the science of anthropometrics and integrated such ideas into his patternmaking system (1903, pp. 9 - 25). When placing his claims in a historical context we must realise that tape measures, pattern-drafting from mathematical formulae and anthropometrics would have constituted cutting-edge science at the time. Thereby, Wampen was indeed adopting new scientific ideas. However, such cutting edge sciences of the 19th and 20th century are now commonplace in modern patternmaking. To a modern fashion patternmaker these techniques may appear rigorous and grounded in science, yet to a fashion technologist viewing traditional techniques in their historical context such methods will seem antiquated. The point is that modern patternmakers need to develop techniques based on modern science, not ideas which were cutting-edge centuries ago.

Having said all this, the fundamental mathematical principles of fashion patternmaking have not changed in hundreds of years. The fashion patternmaker Bray states that "fashions change but the principles of cutting the flat pattern do not" (Chen 1998, ch. 2 p. 36). Patternmaking systems are always limited in their accuracy if they rely on human judgement and trial-and-error fittings. Technology can certainly be used to automate parts of the fashion patternmaking process, using better anthropometric data, three-dimensional scanners and CAD systems. It is also possible to create garments using more flexible materials, or design less fitted clothing. All these approaches attempt to bypass the limited accuracy of patternmaking techniques, yet they simply do not address the fundamental limitations of these traditional methodologies.

The search for new scientific methodologies

Fashion technologists are well aware that many of the techniques used by fashion patternmakers are antiquated, and are often incompatible with modern technologies. Watkins states:

> "Empirical pattern construction methods emerged to assist in speeding up the garment production process. This was achieved within the limitations of the available technology, but this approach to pattern design is inappropriate for today's technology. Now is the time to re-examine and try to access the theories behind these fitting methodologies so that they can be re-interpreted objectively for the ever more sophisticated technologies that are emerging" (2011, p. 245).

There is a pressing need to re-evaluate the application of fashion patternmaking techniques in the context of modern scientific ideas and fashion technology. It is in fact the systemic inaccuracy of fashion patternmaking that led modern researchers to search out new scientific methodologies. Many researchers hope that technological advances in computing and three-dimensional scanning will improve patternmaking processes. Kwong describes how:

> "To reduce trial and error in fitting and measuring, and to expand the use of the computer as a tool for quantification and plotting, many researchers have contributed to the evolving scientific methodology of pattern alteration as an alternative to the hand-drafted empirical approach" (2004, p. 201).

Efrat (1982) sees a new scientific methodology as a necessity, due to the lack of skilled tailors and our increased dependence on mass-produced garments:

> "Today, with the demand for an instant good-fitting garment, and when the number of people with the necessary experience to deliver these well-fitted garments are too few to satisfy the demands, an established scientific relationship between body shape and pattern shape is of fundamental importance" (Efrat 1982, p. 35).

There can be no doubt that this search for a new methodology has become important to the mass-produced clothing industry.

The development of patternmaking methodologies that can work with new technologies has amplified the importance of fields such as fashion CAD systems. CAD systems are commonplace in the fashion industry, specifically for increasing the speed of manipulating flat patterns. Yet, a CAD patternmaking system that can reliably translate three-dimensional figures into accurate flat patterns remains elusive. The fashion technologist Chen wrote a PhD thesis investigating three-dimensional garment design (1998) and in it offers many criticisms of 3D to 2D CAD patternmaking systems. She states CAD software such as 2D-PDS "has not yet provided viable assistance in bridging the gap between design concept and pattern making technique." (Chen 1998, ch. 3 p. 3). She further found little evidence of 3D to 2D CAD systems being successfully employed in the fashion industry without the intervention of a skilled patternmaker.

Fashion CAD programs still depend for their operation on skilled patternmakers. Chen states that a working CAD system would "require traditional manual patternmaking methods because electronic pattern stability has not yet been confirmed" (Chen 1998, ch. 3 p. 3). She states:

> "It would be of great value for the future of the garment industry if manual pattern cutting expertise could be adapted to modern 3D CAD technology and enable patterns to be made effectively and efficiently at the pre-production stage" (Chen 1998, ch. 3 p. 3).

It is clear that a new patternmaking methodology can help improve the accuracy of the ready to wear clothing industry. Further, finding new theories and methodology for patternmaking is doubly important since the bulk of clothing produced is ready to wear.

> "Currently, the individual tailor is less commonly employed and most of the made-to measure garments are today processed through the hands of the large multiple tailoring organisations" (Efrat 1982, p. 26).

From mass-market to high-end designer garments, manufacturers are an essential part of fashion design. Yet many of the patternmaking techniques are built on the assumption that they will be able to accommodate multiple fittings or alterations, which is simply not possible in ready to wear.

Efrat describes the situation:

> "Currently, in the ready-to-wear trade, where prices have become so much more competitive, engineered garments are the accepted standard." (1982, p. 22). Despite the rich heritage of many traditional techniques, most production techniques must be optimised for mass production. This has placed increased importance on ready to wear retailers, clothing sizing systems and anthropometric surveys. In addition to the traditional production techniques new technologies such as three-dimensional scanners and more sophisticated CAD programs have emerged to facilitate production."

Limitations of linear measurements

One of the greatest limitations on fashion patternmaking is its reliance on linear measurements to interpret the three-dimensional form of the human body. This is important since these measurements fundamentally determine the look, fit and feel of the garment. The problem is not confined to fashion but also appears in anthropometrics. Watkins describes how:

> "The measurement of human subjects is generally regarded as more of an art than a science, because of the complexity of the human form. The ability to obtain the same value for a measurement of an individual subject when measured several times in succession is related to the way that landmarks are identified and measuring tools are used, and is a skill that is developed through practice. The problem is compounded when more than one person is taking the measurements" (Watkins 1995, p. 268).

The fashion technologist Istook similarly describes how fashion designers' use of tape measures has historically been "time consuming, invasive, and often inaccurate, based on who took the measurements and how they took them." (2008, p. 94). Linear measurements undoubtedly cause complications in different patternmaking systems.

A fundamental problem that occurs when taking body measurements is translating the curved measurements of the bodying into flat linear measurements. Whife's (1965) research is especially insightful, offering diagrammatic examples that demonstrate the limitations of linear measurements translating into circumferential measurements of the body. Most of this research is directed to women's bodies, in that they have a greater diversity of shapes and are a greater challenge to fit. Whife demonstrates that female figures that have the same circumferential measurements can be completely different three-dimensional shapes. Figure 2 shows three women with the same bust, waist and hip measurement, but displaying very different body shapes. He describes how bras and foundational garments can easily change the shape of the bust and consequently its measurement (Whife 1965, p. 4). He tries to make sense of the situation by looking at what he calls the "thickness through", which is a cross-section of the body (see Figure 3). Taking such a cross-section of the body can help to illustrate that a single circumferential measurement can represent a wide variety of complex body shapes.

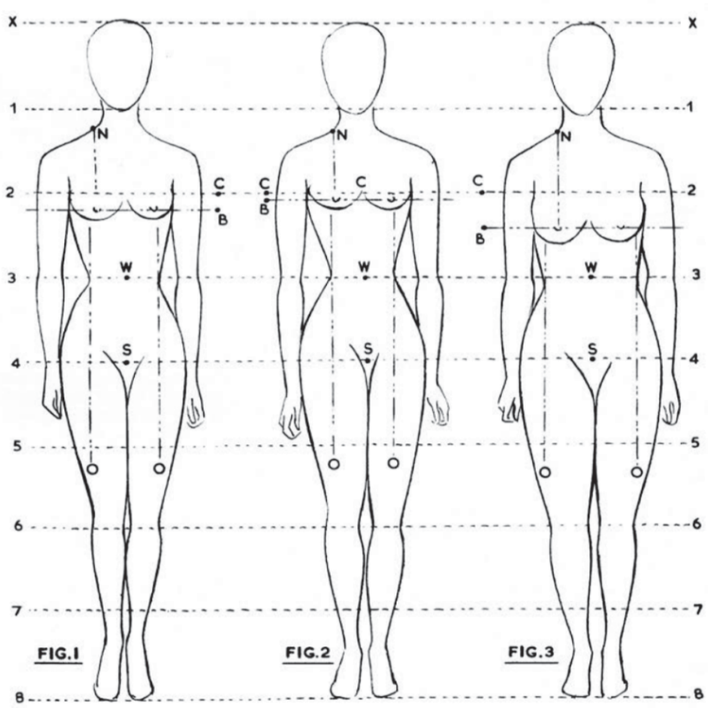


Figure 2: These figures have the same bust measurements, yet have completely different three-dimensional forms (Whife 1965, p. 7).

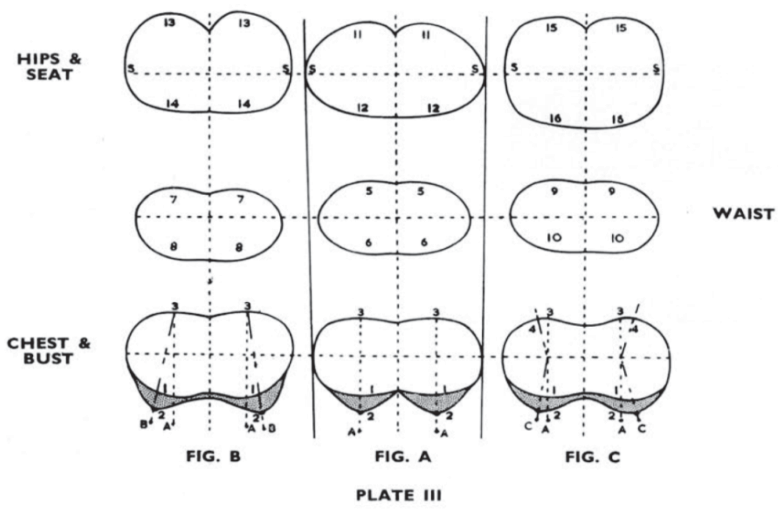


Figure 3: Cross-sections of the three figures with the same bust measurement but different three-dimensional forms (Whife 1965, p. 4).

A clear problem we encounter when taking circumferential measurements of body parts is their position relative to each other. Whife (1965, pp. 7 - 8) makes the precise observation that the majority of patternmakers pass the tape measure around the back of the figure and take a measurement on the fullest part of the body. Taking this measurement is like cutting a horizontal cross-section of the body (see figure 3). Whife describes this process as akin to looking from above at a body that has been surgically cut through (1965, p. 4). However, these cross-sections are not always horizontally parallel to the ground. In an ideal scenario all the measured cross-sections would be perfectly parallel to the ground. Instead Whife makes the observation that the hips, waist and bust tend to slant and project at different angles. In figure 4 (1965, p. 10) Whife shows the same models in figure 2 (above) from a side view. These women have the same circumferential measurements, but very different body shapes. The busts of different women tend to project outward at different angles depending on their altitude and shape. The hips and waist also slope at different angles, and taking measurements at these angles can distort body measurements.

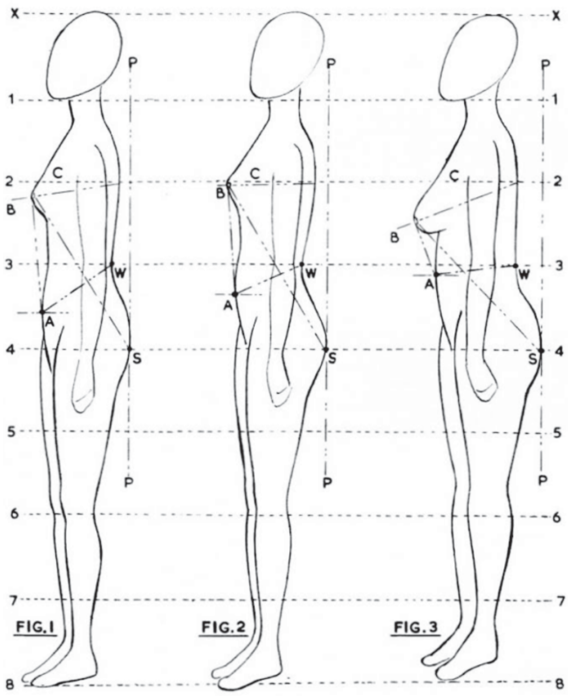
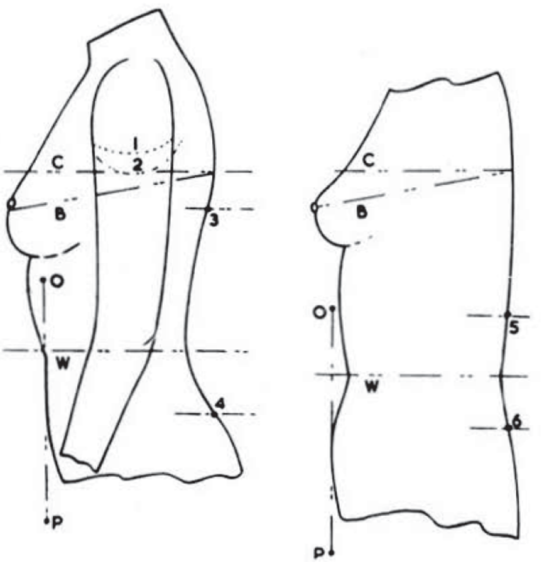


Figure 4: Side view of figures with the same bust measurements. These can still have completely different three-dimensional forms (Whife 1965, p. 10).

In an ideal body-measurement scenario it is common for all circumferential measurements to be horizontally parallel to the ground, and this is the process used by three-dimensional scanners to map the body. However, identifying body landmarks and taking body measurements can be variable and quite subjective. Using a tape measure often leads to a measurement whose cross-section is angled and not parallel to the ground (see figure 5). Further, in figure 6, Whife (1965, p. 12) demonstrates how linear measurements become less accurate when working with non-ideal or "abnormal" body types. He deftly identifies scenarios where different body shapes can exacerbate the difficulties of taking linear measurements.



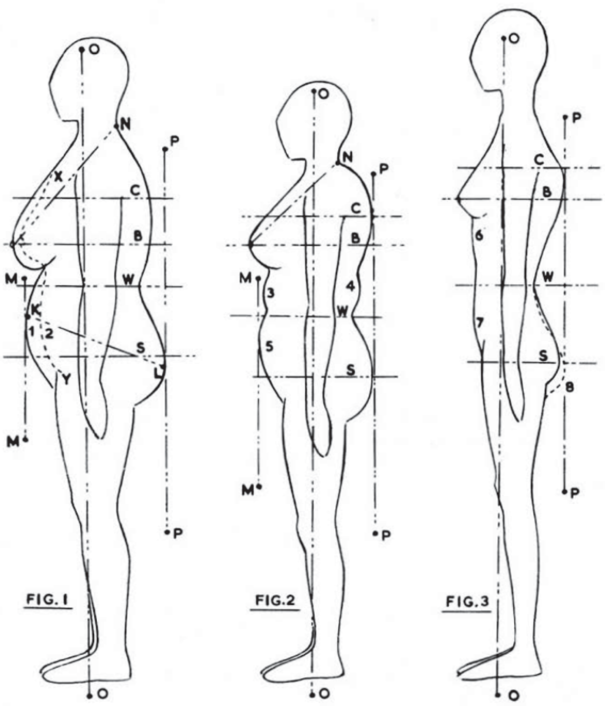


Figure 5: The measurement is often no longer parallel to the ground when taken with a tape measure around the fullest part of the bust (Whife 1965, p. 6).

Figure 6: Problems with taking linear measurements become excacebated when working with full-figured or non-ideal body types (Whife 1965, p. 12).

Whife identifies women with body types that are fleshier, hunched up or have prominent shoulder blades (1965, pp. 11 - 13). As soon as the body becomes more curvaceous the tape measurements that capture the fullest part of the body are greatly angled and distorted. This deviation is not so obvious on ideal body shapes (such as figure 4) but becomes so with the more curvaceous shapes of figure 6. Women with such curvaceous shapes tend to strain the accuracy of linear circumferential measurements. Whife remarks that these body shapes "present problems of cutting and fitting which are not solved entirely by inch-tape measurement." (Whife 1965, pp. 11 - 12). Thereby, fitting body shapes becomes increasingly complex and less accurate as the figures deviate from the idealised figure.

One of the difficulties of measuring the body is that patternmakers must identify and measure body landmarks. This means that they must first identify the part of the body to be measured and then take an accurate measurement. Chen states:

> "Where the landmark should be placed is a source of controversy, and not only differs from one measurer to another, but also from one country to another. It can also vary if a measurer measures a subject a second time" (1998, ch. 2 p. 20).

Defining where a body landmark is can indeed be very subjective, due to the diversity of body shapes. Thornton describes the inaccuracy of identifying body landmarks such as the neck point, and taking accurate measurements. He states:

> "…But he, nor any cutter taking this measure, could not take it twice alike. It was the most illogical arrangement ever devised, but it has lingered on in some modern methods to the bewilderment of all using them" (Thornton 1949, cited in Kunick 1984, p. 5).

All in all, the subjective nature of these measurements has built a degree of inaccuracy into fashion patternmaking.

The usefulness and reliability of circumferential measurement is also questioned by experts. Bray points out that the difficulty of applying contoured measurements to a flat surface is that the "results are bound to be somewhat approximate, and inaccuracies have to be allowed" (1994, p. 12, cited in Chen 1998, ch. 2 p. 11). The fashion technologists Faneii-Beck and Pouliot found that it is not easy to alter the fit of trousers since the contoured shape of hip and thighs could not be determined from traditional methods of measurement (1983, cited in Kwong 2004, p. 200). Further, the patternmaker Poole states that his golden rule for both men's and ladies garments is "shape matters, not size" (1927, p. 319, cited in Chen, 1998, ch. 2 p. 11). This epithet seems to suggest that fitting clothing to the contours of the human body will always involve some inaccuracy, requiring the intervention of human judgement.

Limitations within anthropometric systems and sizes

The prevalence of ready to wear manufacture puts greater reliance on anthropometric data and sizing systems. Otieno explains that at its core anthropometrics is about accurately measuring the body, analysing the vast data into efficient size charts, and using the size charts in marketing to create customer satisfaction (2008, p. 71). Size charts are likewise important to determine efficient production, styling, pattern designing, fabric quantities and making up (Chen 1998, ch. 2 p. 26). They are used in turn as marketing tools for the manufacturers and retailers, for size discernment and for communication to consumers (Otieno 2008, p. 74).

The objective for retailers is to fit the maximum number of people within the minimum number of sizes. Manufacturers and retailers similarly want charts that are concise, economical and offer consistent intervals of sizes (Otieno 2008, p. 82). Despite efforts to increase the efficiency of these systems there are still many issues that fashion technologists are critical of (Otieno 2008, pp. 74 - 75). Problems with sizing systems are meanwhile commonly encountered by customers. Winks states

"Many examples of sizing inconsistency and variety could be quoted, but they can be encountered personally by random visits to shops." (1997, p. 2). Yet sizing systems are marketed to the consumer as solutions to all their problems. For their part, fashion technologists hold a more complex view of anthropometrics, observing that sizing systems are limited in the range of bodies they can fit. Otieno explains that:

> "Although the usefulness of anthropometric data in developing effective sizing systems has been recognised for many years, its utilisation has neither been uniform nor a panacea for all problems" (2008, p. 75).

Sizing systems do create the impression for the customer that they are standardised and universal. Istook notes that "Unfortunately, the sizing systems that have developed through the years are neither standardized nor related to the average human's body measurements." (2008, p. 94). Yu similarly remarks that "Definitions of human anthropometric and related terms have varied from country to country and from time to time." (2004, p. 190). The system of retaining a single-size code that can capture all the critical measurements of a garment has real limitations.

In reality, to create sizing systems is more like inventing a set of guidelines that try to capture the greatest proportion of the population. There are severe difficulties in positing any form of universal or standardised system for garments. Winks describes just how many different systems of size codes there are, and states:

> "They can vary substantially not only from one garment type to another, but within the same garment type; not only from one country to another, but within the same country and even within the same shop. Nor does the sizing system for one branch of the clothing industry coincide with that for another" (Winks 1997, pp. 2 - 3).

This sentiment is reinforced by Otieno who discusses how "There is variation within and between companies and countries. National and international standards exist but often provide varying information." (2008, p. 82).

Despite attempts to organise a universal standard of sizes, in practise garments are generated to sizes independently created to suit the needs of their target market. Yu describes the historical development of sizing systems (2004, pp. 174 - 177), remarking how in the twentieth century each country independently developed their own measurements surveys and clothing sizing standards. Winks describes how:

> "Up to 1991 there had been no internationally-accepted system for sizing the whole range of children's, women's and men's garments, and accessories. Manufacturers make garments to their own size specifications, basing these upon their own or their customers' experience or, alternatively, of the retail houses or wholesalers they supply. Some garments are sized according to garment dimensions, length or chest measurement, and a further variety by arbitrary systems adopted at random by manufacturers of certain garment types" (Winks 1997, p. 1).

Even with modern attempts to create clothing standards, many experts disagree that an actual standard has been created. Yu states that "the standardisation of sizing systems has been debated for a long time, and the acceptance of such a standard is sometimes in question." (2004, p. 193). Even within the definition of size codes there is room for ambiguity. Kunick describes how a size code is "to imply, not that it is an exact size, but that it is nearer to that particular size than any other" (1984, p. 12). Certainly, this reality has spawned a myriad of challenges for sizing systems.

Experts identify problems in standardising clothing into different sizing systems. This is because each part of the clothing industry uses different sets of measurement in its own way and for different purposes. Winks is critical of how:

> "The systems for men's wear, women's wear, and children's wear are as different as chalk from cheese. The skirt industry, the knitwear industry, the hosiery industry, the foundation garment industry, the sock-, glove- and hat-industry, each has its own ideas of sizing, and of size labelling, mostly hampered by traditional practice so that progress towards provision of enlightened consumer information has been stultified" (Winks 1997, pp. 2 - 3).

This situation has turned size codes into a tool to help assist consumers choose apparel, yet these numbers are arbitrary and represent entirely different systems of measurements (Yu 2004, p. 188).

The accuracy of measurement data and the way they are applied is also questioned. "To provide valid body measurements for all populations, one would need to do the impossible task of measuring each and every individual."(Otieno 2008, p. 75). Survey data remains essentially an estimation of the population, limited by the size of the survey and the expertise of people taking the measurements.

Another key issue affecting anthropometrics is the subjectivity of acquiring measurements from body landmarks. Accurately measuring landmarks is a trial because they rely on identifying bone structures which are beneath the skin and different in each individual. Yu describes how the process of measuring body landmarks provides greater speed in taking body measurements (2004, p. 169). Otieno however, is critical of this procedure, stating:

> "Although landmarks show the beginning and end of a dimension, their determination and measurement can be inaccurate and variable, resulting in invalid and unreliable data" (2008, p. 75).

And:

> "The lack of relevant, valid and current anthropometric data has resulted in the use of unreliable size charts and systems. Different procedures are used to measure the same variables and this makes it difficult to compare data" (Otieno 2008, p. 75).

Our brief survey leaves no doubt that many challenges remain concerning the use of body measurements relative to anthropometric data.

Limitations of the ideal body type

One of the limitations of sizing systems is their reliance on fitting to "idealised" or "average" body shapes. The problem with turning anthropometric data into "average" sizes is that many people will be a similar shape to the average size, but very few will be the exact size of the "average". This is what some experts call the "average body fallacy" which assumes that every person of any shape and size can fit into average sizes (Otieno 2008, p. 78). Clothing companies give their sizes a shape considered "ideal" and this is reflected in its proportions, contours, symmetry and posture. "However, due to heredity, ethnic origin, growth patterns, disease or accident, the figure of the individual may vary from the standard" (Kwong 2004, p. 200).

There are people with disabilities and special needs who require clothing of different shapes and functions to conventional clothing. Patternmaking books for disabled people such as Goldsworthy's *Cloths for disabled people* (1981) is a niche source of information for people who often need to have their clothing custom made for individual requirements. In this literature the notion of "ideal" or "average" bodies is not applicable. Patternmakers are forced to create unique designs and cannot rely on conventional techniques. Fashion designers such as Alexander McQueen have used models with disability and disabled bodies in his *Fashion-Able* photoshoot in Dazed and Confused Magazine (Watt 2012, pp. 152-153). These theatrical photoshoots explore the aesthetic possibilities of non-ideal bodies. Clothing is a powerful source of expression and self-representation no matter your body shape.

Moreover, people with non-standard figures are not just those with disabilities or special needs. Every individual is different and our bodies all show idiosyncrasies. Watkins describes the “average man” paradox as a reaction to the extreme variations of individuals in the population and the attempts of anthropometric data to find averages (1995, pp. 268 - 269). Chen asserts the notion that the ideal body type does not exist because it relies on averages of unreliable measurements (1998, ch. 3 p. 78). One of the limitations of sizing systems is that they do not have sufficient range of sizes to fit all body shapes and sizes. Kwong is critical of how mass production strategies have made it “virtually impossible to meet the needs of those individuals who have special fitting requirements” (2004, p. 203). “In essence, many people whose body proportions do not fall in these categories have no choices” (Otieno 2008, p. 78).

Traditional patternmaking techniques are also limited by the way they use idealised figures in their practise. Mannequins used to drape and fit clothing represent an idealised body and thereby only fit a single static form. Efrat’s studies identified many experts who observed that the workroom mannequin did not represent the normal human figure (1982, p. 41). Since mannequins are complex three-dimensional shapes, standardising their sizes in the industry is very difficult. Moreover: “companies tend to make their own dress forms which represent the body figures of their target customers.” (Yu 2004, p. 35). Liechty et al. similarly observes how the proportions of the ideal figure are subjected to change according to the whims of fashion (1995, p. 34, cited in Chen ch. 2 p. 13), and laments how few individuals actually conform to these standards, notwithstanding that they will become the basis for ready to wear and commercial patterns. Ideal body types and mannequins are a necessary part of garment manufacture, despite their limitations. In truth, the only sector of fashion that can afford to have custom mannequins is haute couture. Yet even a custom mannequin may not resolve all fitting problems, since couture requires multiple fittings.

There are meanwhile experts who challenge the ability of a static idealised shape to fit the human body at all. While a mannequin is a static representation of a human, the body is constantly changing shape when we move, breathe or eat. Chen is critical of how rarely garment technologies can perform a satisfactory fit on the body by merely using a garment stand (1998, ch. 2 p. 9). Obviously, a live body dynamically moves and changes shape. She argues that:

> "A garment stand is an average body figure which does not exist in reality; therefore, it is necessarily an ineffective method for providing basic criteria" (Chen 1998, ch. 2 p. 9).

In practise, live models are often used to test the fit of clothing. At best, it is unlikely that the live model has the exact same three-dimensional form as the mannequin. This makes the use of a life model more of a guide or approximation, a "help" in fitting the garment. In order to standardize fitting, procedures have been developed so that the live models can evaluate the clothing fit (Yu 2004, p. 34). Such procedures are extremely useful for identifying designers' and patternmakers' fit problems, but one limitation of this practice is that the models "…tend to make judgements based on subjective and qualitative preferences which vary from one person to another from time to time" (Yu 2004, pp. 33 - 34). In short, the limitations of static models and the subjective judgements of live models make it very difficult to objectively define garment fit.

The limited accuracy of fashion patternmaking is a problem experienced by fashion manufacturers and their customers alike. There are many people who do not fit within sizing systems and are affected by the limitations of anthropometric patternmaking systems. Otieno (2008, p. 73) describes the difficulty and frustration of finding fitted clothing for customers who are not the so-called "average size". He describes how:

> "Achievement of garment fit is evasive. From body measurement to purchase, sizing issues pervade the supply-chain processes. Today, many people not only live with the difficulties of finding clothes that fit but also suffer the subsequent confusion about garment sizing" (Otieno 2008, p. 73).

Reliance on the patternmaker's subjective experience

We have exhaustively noted that patternmaking systems place a heavy reliance on the skill and personal experience of the patternmaker. These skills may seem intangible or *tacit,* but their application is always essential to fashion production. Watkins shows how pattern construction and fitting techniques have historically required tacit knowledge (2011, p. 245). Whife is insistent that the term "rock of eye", which is the skill of the patternmaker to make accurate judgements, has become synonymous with guessing. He speaks of how "observation and judgement are very real things - and they should be held as important by every cutter." (Whife 1965, p. 1). While he moves to describe how a tailor "should make efforts to train his observation and to develop his judgement; he will need both in almost every moment of his daily work." (Whife 1965, p. 1), he makes the point that it does not mean that a tailor can entirely abandon his tape measure. Watkins in turn describes how it is generally up to the individual patternmaker to interpret how closely a garment conforms to the body (2011, p. 246). Clearly, the critical dependence on these skills puts limitations on the consistent fitting of garments to the body.

By contrast, the skill and artistry of patternmakers who drape fabric on a mannequin cannot be underestimated. Unlike other materials, fabrics have the "ability to undergo large, recoverable draping deformation by buckling gracefully into rounded folds of single and double curvature." (Hunter & Fan 2004, p. 114). While this is simply known as "drape", it takes a patternmaker years of experience to master. Draping is extremely useful, as it:

> "Together with the effect of seams, determines the way in which a garment moulds itself to the shape of the body, this being a critical factor in comfort and aesthetic-related aspects of a garment and its fit" (Hunter & Fan 2008, p. 8).

Chen describes how "the tacit knowledge of the body form gained by 3D block development is valuable when using 2D pattern methods for mass production" (Chen 1998, ch. 2 p. 38).

The draped garment has the advantage in that it provides an actual body form as well as a real garment in three dimensions. Chen remarks that "it is possible that most of the disagreements about a garment form or fit could be eliminated where there is an available, agreed 3D garment foundation form" (Chen 1998, ch. 2 p. 38). Draping on a live model is also the only opportunity patternmakers have to test fittings on a model that moves, breathes and can describe how comfortable she or he is (Chen 1998, ch. 2 p. 37).

Since Drape is established as a very intuitive and subjective practise, it is extremely difficult to analyse from an objective point of view. Kwong states: "Although drape is usually assessed subjectively, considerable research has been carried out with a view to its objective measurement, and to relate the drape, so measured, to objectively measure fabric mechanical properties, notably bending and shear stiffness" (Kwong 2004, p. 115). There are complex factors here, requiring skills from many disciplines. Viewed from an objective perspective "Drape is therefore a complex combination of fabric mechanical and optical properties and seam properties, as well as of subjectively and objectively assessed properties. Furthermore, there is frequently an element of movement" (Hunter & Fan 2008, p. 8). The sheer amount of data and parameters needed to define each aspect of drape can be overwhelming. This tends to polarise the approaches taken by researchers trying to understand and improve the techniques.

It is clear that reliance on the subjective skill of the patternmaker can limit our understanding of patternmaking and stifle the development of new techniques. Researchers are often polarised into those who rely on the subjective skills of the patternmaker and those who completely neglect them. Traditional patternmakers tend to place great emphasis on individual subjective skills, assuming that a patternmaker with enough skill can solve any problem. They often ignore the possibility of systemic problems built into the patternmaking system itself. Alternatively, fashion technologists such as computer CAD developers tend to ignore the skills and judgement of the patternmaker, making the assumption that by automating fashion patternmaking systems with new technology they can solve all fitting problems. They perennially overlook the ways in which a patternmaking system is reliant on the patternmaker's judgement. Such technologists are not always able to capture the careful decisions that a patternmaker chooses. While Huang et al. identify many examples of computer algorithms which will generate a fitted pattern to the body (2012, pp. 680 - 683), and while these algorithms may be well based on different mathematical theories, the patterns tend to be completely inaccurate or unusable in practise. Huang et al. (2012) suggest this is because these algorithms fail to incorporate an understanding of traditional concepts and techniques. New ways to analyse how traditional practises work while simultaneously being grounded in a rigorous framework, offer the opportunity to improve our existing patternmaking systems.

Underlying limitations of intuition

Traditional patternmaking literature places great importance on a patternmaker's intuition, judgement and experience. Visionary designers are seen as having virtuosic skills by relying solely on their intuition. Intuition and experience take on mythical properties, and it is assumed that when a patternmaker becomes skilled enough their intuition will transcend the need for any formalised set of procedures. Discussing intuition is difficult because it is so intangible, and finding a formalised way to teach or even record high-level skills has always been elusive in patternmaking literature.

To make sense of the esoteric phenomenon of intuition, it is possible to use the research of the Nobel prizewinning psychologist Daniel Kahneman. Through his psychological research Kahneman demystifies the mythology behind expert intuition and attempts to explain it as a phenomenon of pattern recognition (2011, pp. 10 - 13). He analyses individuals who achieve seemingly miraculous feats of expert intuition, describes examples of chess masters who can see the outcome of a game after merely glancing at the board, firemen who know to run out of a burning building due to a slight change in temperature, or physicians can make an instant diagnosis upon seeing the patient (Kahneman 2011, p. 11). Yet Kahneman also observed that as humans we do things that are equally miraculous but far more common. We are pitch-perfect in detecting anger in the first word of a telephone call, can sense if we are the topic of conversation when entering a room or notice the subtle signs that the driver in the car in the next lane is dangerous (Kahneman 2011, p. 11). Kahneman states that "expert intuition strikes us as magical, but it is not. Indeed, each of us performs feats of intuitive expertise many times each day.". He explains that "our everyday intuitive abilities are no less marvelous than the striking insights of an experienced firefighter or physician - only more common." (Kahneman 2011, p. 11).

Kahneman, in researching the psychological mechanisms responsible for expert intuition, indicates that an expert will take cues from a situation and will recall experiences from memory. He cites the work of the psychologist Herbert Simon, stating that "the situation has provided a cue; this cue has given the expert access to information stored in memory, and the information provides the answer. Intuition is nothing more and nothing less than recognition" (Kahneman 2011, p. 11). Understanding this heuristic of pattern recognition helps us to grasp some of the more advanced techniques of expert intuition.

Kahneman describes how the human mind can make two very different kinds of judgement. He calls these two systems of thinking "System 1" and "System 2" (Kahneman 2011, p. 11). System 1 thinking is quick, instinctive and emotional. System 2 thinking is slower, more deliberate, more analytical. Intuition uses system 1, while system 2 requires much more effort to use. System 1's intuition relies on an expert remembering experiences from the past, while System 2 requires the careful analysis of new information. The use of system 1 thinking can offer impressively quick results, yet there are many instances where slower analytical thinking is more important than such quick pattern recognition.

Kahneman's work also identifies that it is possible to have bias or systemic error in intuitive thought patterns. He describes how "one of the more important developments is that we now understand the marvels as well as the flaws of intuitive thought" (Kahneman 2011, p. 10). He discusses how System 1 (intuition) engenders systemic decision-making bias that constantly violates the rules of rational choice (Kahneman 2011, p. 10). "Systematic errors are known as biases, and they recur predictably in particular circumstances" (Kahneman 2011, pp. 3 - 4). He further cites examples where using a heuristic or rule of thumb to make a judgement will create predictable biases or systemic errors (Kahneman 2011, p. 7).

The notion that the mind is susceptible to systematic errors or bias is now generally accepted by the scientific community (Kahneman 2011, p. 10). Further, the idea that heuristics create bias has been used by scholars in diverse fields such as: medical diagnosis, legal judgment, intelligence analysis, philosophy, finance, statistics, and military strategy (Kahneman 2011, p. 8). In fact, due to fashion patternmaker's heavy reliance on intuition, most patternmaking techniques are recorded as heuristics, so that clearly, it is plausible from the limitations of existing techniques that some bias or systemic error can be built into fashion patternmaking.

In response to Kahneman's research, one of the ways to bypass the systemic bias of intuition would be to systematically examine the phenomenon of patternmaking. This would be achieved (bypassing the mythology, anecdotal advice and rules of thumb) by objectively analysing the phenomenon using geometry. This would constitute more analytical, slower System 2 thinking, overcoming the systemic bias of rapid, emotionally-based System 1 thinking.

Inconsistency of the definition of fit

While clothing fit is of the utmost importance to patternmakers, to define exactly what clothing "fit" is, and how to maintain it, is a challenge. Yu argues:

> "The principles of fit are (however) not clearly understood, and definitions of fit vary from time to time, and depend on the fashion culture, industrial norm and individual perception of fit" (2004, p. 31).

The term fit can cause confusion in the garment industry by being used to describe different attributes (Chen, 1998 ch. 2 pp. 57 - 58). It can be used to refer to an aesthetic or style choice such as a close-fitted or loose-fitted garment. Another definition refers to the way the clothing conforms to the body. This definition can be subjective, as we all interpret the feel of clothing in diverse ways. The term is in fact problematic because it is applied inconsistently, compounded by a general lack of agreement about the essential elements (Morgado 1996, cited in Chen 1998, ch. 2 p. 55). Chamber and Wiley meanwhile offer more pragmatic definitions:

> "Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer" (1967, cited in Yu 2004, p. 31).

Shen and Huck likewise offer a useful definition: "Clothing which fits, provides a neat and smooth appearance and will allow maximum comfort and mobility for the wearer" (1993, cited in Yu 2004, p. 31). Despite all this, clothing "fit" continues to evade an objective standard, and remains heavily reliant on the subjective experience of individuals.

Limited understanding of movement

Fashion patternmaking in general has been limited by lack of understanding of the effect of movement on patterns.

> "While changes in technology have made great advances in the measurement of body movement, the advances in methods to apply that data to clothing design have taken place at a much slower pace" (Watkins 1995, p. 240).

Patternmaking is fundamentally about designing clothing to accommodate the movement of the body (see figures 7, 8, 9 and 10 below). Yu describes how "the human body is constantly changing, even when standing still. Movement due to swaying, breathing and posture changes during scanning can readily affect measurements, such as the chest circumference" (2004, p. 165). Yet patternmaking records static shapes, and when it comes to movement there are limited options for recording and analysing information.

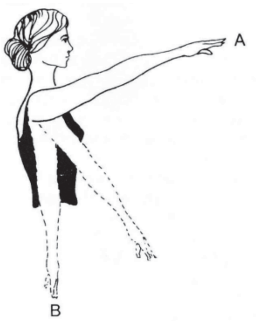


Figure 7: "(A) Flexion of the arm; (B) extension of the arm" (Watkins 1995, p. 222).

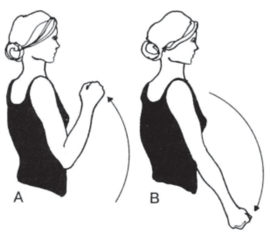


Figure 8: "(A) flexion of the elbow; (B) extension of the elbow" (Watkins 1995, p. 222).

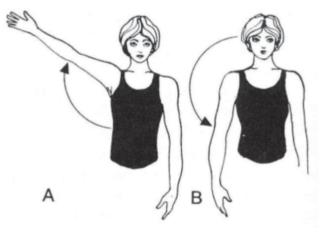


Figure 9: "(A) abduction of the arm; (B) adduction of the arm" (Watkins 1995, p. 222).

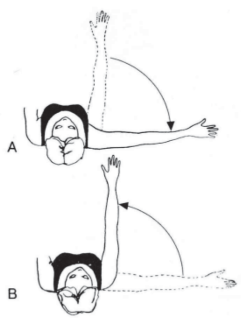


Figure 10: "(A) horizontal abduction of the arm; (B) horizontal adduction of the arm" (Watkins 1995, p. 223).

The process of accommodating a range of movement into a garment is by testing the garment on the wearer and adjusting the pattern using trial and error fittings. Even within these fittings there is no way to precisely record a range of motion; the range of movement will always be judged by the subjective experience of the patternmaker. Addressing the movement of the body is one of patternmaking's greatest challenges (see figures 7, 8, 9 and 10), yet in practise there is very little that can be done to record and analyse it.

Further, patternmaking systems sometimes fail to understand the sheer complexity of human body movement. The body is alive, constantly moving and changing, its range of motion so intricate that the simplified ways patternmakers use to analyse the body can fall short. Patternmakers are well familiar with the concept of "ease", which allows additional volume in a pattern for involuntary movements such as breathing or sitting down (Watkins 2011, p. 247). Beazley in turn describes how the simple act of breathing can affect the waist girth by up to 2cm (1996, cited in Chen 1998, ch. 2 p. 12), not to mention that bodily functions such as eating, affect the wearer. A change in body posture can change the entire fit of a garment, and customers are notorious for posing while being measured (Efrat 1982, p. 10). This plainly leads to inaccuracies whereby measurements are taken for an unnatural stance. Further, Perry notes that improper posture may cause fitting problems (1972, cited in Kwong 2004, p. 197). He cites how when a posture is extremely erect the distance from the back of the neck to the shoulder-blade becomes shorter and the distance from the base of the neck to the apex of the bust lengthens. The contrary to this occurs when the figure is slumped forward. A single change in posture can completely change the fit of a garment. Larson found that the fitting of trousers is not only affected by the wearer's measurements and contours but also their posture (1994, cited in Yu 2004, p. 198). Plainly, movement has such an impact on patternmaking whereby concepts that try to approximate its complexity are inadequate.

Movement studies have been adopted in many fields of research, yet patternmaking technology has lagged behind. Movement studies have been undertaken in fields as diverse as anthropology, aerospace science, dance, industrial safety, medicine, physical education, physical therapy and psychology (Watkins 1995, p. 226). To map the motion of a single joint in the body may seem a simple task (see figure 11); however, within the human body there are several joint types, which can create a complex range of motion (see figure 12). These include: hinge, saddle, condyloid, ball and socket and pivotal joints (Ashdown 2011, pp. 278 - 279).

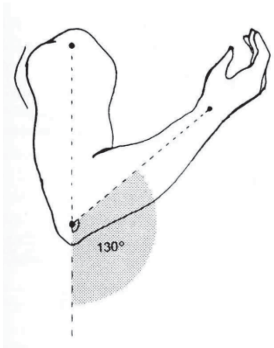


Figure 11: The range of joint movement of the elbow flexion (Watkins 1995, p. 223).

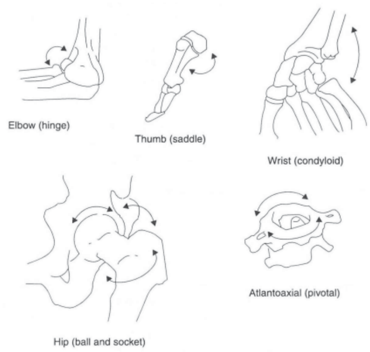


Figure 12: Examples of the five main joint configurations and how they move (Ashdown 2011, p. 279).

Fashion patternmakers can learn from certain anatomical studies developed by scientists. Hutchinson (1970, cited in Watkins 1995, p. 227) identifies "Labanotation", a type of notation used to show movement and precise positions over time, developed by Rudolf Laban (see figure 13 below). This language allows people to record and communicate the motion of the body (see figure 14). This notation has been used in dance, education, ergonomics, rehabilitation and anthropology (see figures 15 and 16) (Watkins 1995, p. 227). Without a language to record movement, analysis of complex motion would be difficult, and our understanding of such phenomenon would remain superficial. Patternmaking could greatly benefit from such a language.

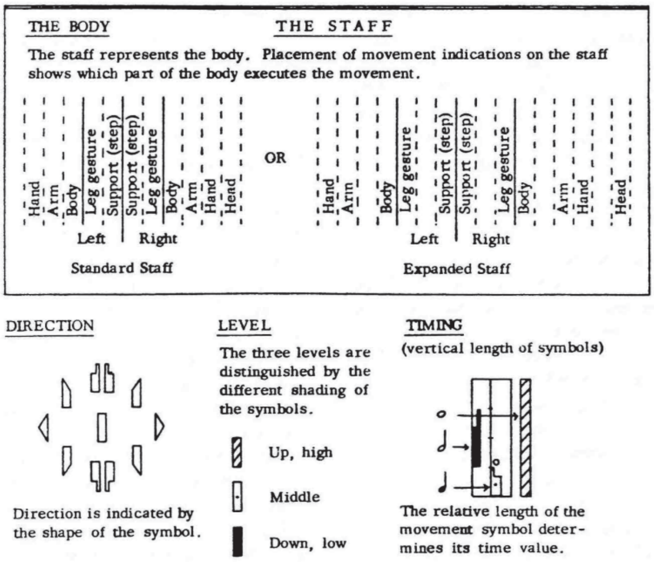


Figure 13: "Some of the basic Labanotation symbols for body parts, direction, level, and timing of movements" (Watkins 1995, p. 228).

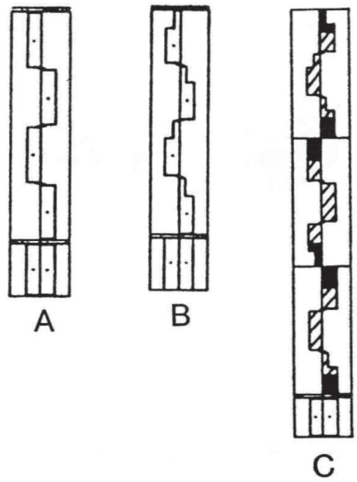


Figure 14: "Labanotation symbols used to depict three different kinds of steps: (A) steps in place marking time: (B) forward steps, a normal walk; (C) a waltz step" (Watkins 1995, p. 228).

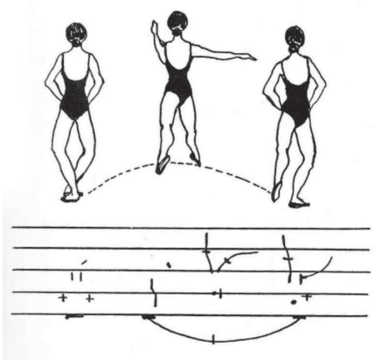


Figure 15: Benesh dance notation (Watkins 1995, p. 229).

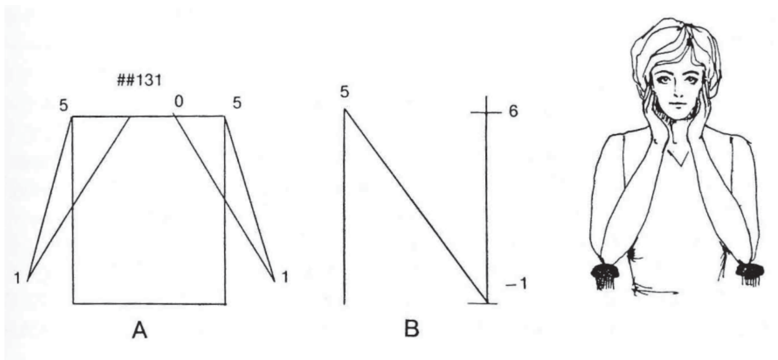


Figure 16: Kinesics notation can be used to show the relative joint angles and body parts. (Birdwhistell 1952, cited in Watkins 1995, p. 229).

Studies have been carried out on skin stretch or "anthropometric kinematics" which measure how the body changes with movement. Kirk and Ibrahim, in exploring the expansion and contraction of the body, used a series of measurements to accurately measure skin strain (Watkins 1995, p. 240). Figure 17 (below) shows how the shape of the back changes as the body moves, and Figure 18 shows changes in the shape of the knee joint. Watkins states that when the knee is bent “the leg increases in length over the kneecap and correspondingly decreases in length along the back of the knee. The circumference of the leg in the bent area may also increase as muscle tissues and fat move into different positions” (Watkins 1995, p. 240). In the case of a fitted non-stretch pair of trousers this causes the fabric to stretch on top of the knee cap, and the excess fabric to bunch up behind. Such observations are confirmed by modern technology such as the three-dimensional scan (figure 19, below) from Cornell University, showing how the measurements of the knee change during movement (Ashdown 2011, p. 292). Such dramatic changes in body shape illustrate how simplistic concepts such as “ease” can barely capture the complexity of human movement.

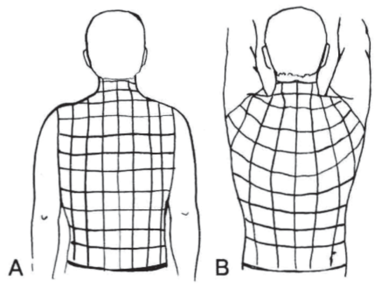


Figure 17: “Skin stretch as an indicator of expansion needs in clothing: (A) precisely measured square blocks drawn on the body at rest; (B) changes in the shape and size of blocks shown when the body moves from the anatomical position” (Whife 1995, p. 240).

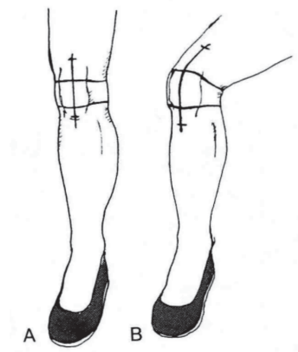


Figure 18: Anthropometic kinematics: (A) Guidelines were marked on the extended knee. (B) The area of the marked area and the measurement over the knee cap increased (Whife 1995, p. 240).

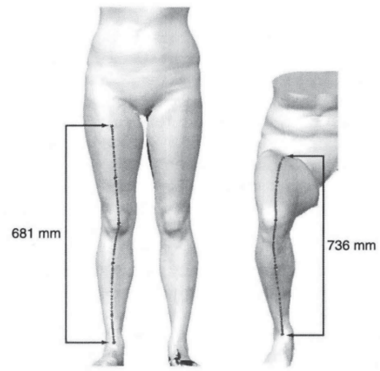


Figure 19: A 3D scan, taken to measure the change in body measurements in different active movements (Ashdown 2011, p. 292).

Movement studies for garments have offered valuable insight into how the body distorts the shape of a piece of clothing over time. Patterns in general fit a single static shape and rely on the flexibility of the fabric and distortion of the pattern to accommodate movement. Watkins describes the practise where slits are cut into the seams of non-stretch garments to measure the expansion and contraction of the body as it moves (Watkins 1995, p. 241). The slit openings of these patterns create shapes that are similar to flat patterns (see figure 20). This insight, showing exactly how a pattern changes over time, suggests that the movement of the body is far more complex than simply adding a few centimetre of ease around a pattern. Making sense of these changing patterns will surely help patternmakers to build better-fitting garments.

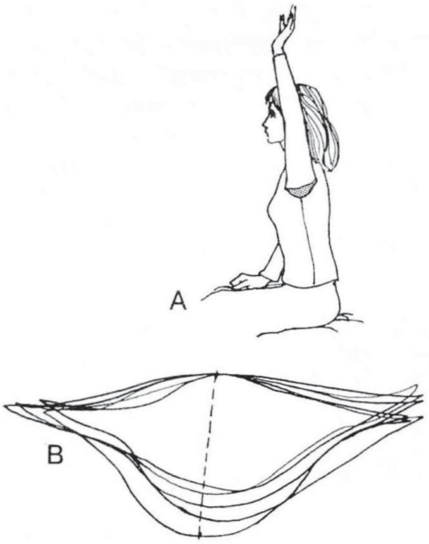


Figure 20: (A) In Atkin's study, a slit was cut into the underarm seam in order to determine how movement affects the body. (B) As the subject moved her arm about her head the size and shape of the opening was traced (Atkin 1980, cited in Watkins 1995, p. 241).

Figure 21: "Wrinkle analysis" (Watkins 1995, p. 243).

Methods exist whereby patternmakers can learn about the fit by looking at wrinkles in the clothing. "Wrinkle analysis" is a method of informally gathering data about the fit (see figure 21, above). Wrinkle analysis tends to work like a rule of thumb, and so can be interpreted by designers in different ways. For example, Watkins (1995, p. 242) suggests that horizontal wrinkles indicate the garment segment is too long or too tight around the body, vertical wrinkles indicate the garment is too short or too loose, and diagonal wrinkles indicate areas where there is insufficient ease in the garment. While these are simply practical tools for making approximations of how to fit a garment, patternmakers such as Liechty et al. (1992) analyse the wrinkles in greater detail. Their goal is to manage the most effective alteration to a pattern. Although this wrinkle analysis is insightful, any system of alterations is still heavily reliant on the patternmaker's subjective skill. Such techniques tend to document a series of fitting scenarios instead of addressing any sort of underlying framework.

Meanwhile, there are several approaches to increasing mobility in clothing. We should note that patternmaking's reliance on flexible fabrics to increase mobility can often overlook patternmaking that is engineered around movement. Watkins identifies two basic strategies for increasing clothing mobility: "selecting a fabric that will move easily with the body and developing a garment design that promotes mobility" (1995, p. 244). He suggests that carefully planning the garment with both of these considerations is ideal (Watkins 1995, p. 244). Ashdown lists further strategies, including:

> "…By loose flowing clothing (excess width, excess length, or both), by unattached areas between garments (separates), by open areas in the garment, by close-fitting clothing made with elastic materials, or by design features that release as the wearer moves, such as pleats or elastic inserts" (2011, p. 283).

All in all, these strategies tend to rely on flexible fabrics and the insertion of "ease" into a pattern. In fact, many strategies to increase mobility involve the addition of "ease". There are several ways to do this, including: adding length or width to a garment; adding pleated or elasticised parts to a garment, and adding extra panels or gussets to a design (Watkins 1995, p. 246). Flexible materials, pleats, gussets and ease offer a "broad" solution to many mobility problems. What is basically overlooked is to deftly engineer the pattern of the garment after learning from the range of movement. This requires an understanding of how the body movement changes the patterns, and how to incorporate this knowledge into the patternmaking. Watkins states:

> "One of the most important aspects of mobility lies in the cut or contour of garments. Subtleties in contour can make a much more important contribution to success in garment mobility than changes in ease or size. Contouring involves planning a design so that when a worker is in his or her most frequently-taken position, the garment fits without strain" (1995, p. 250).

Clearly, our ability to engineer patterns that accommodate movement can be significantly improved.

Some novel solutions for engineering garments for greater mobility have come from garments designed to operate in extreme conditions. Garments such as space suits or underwater suits offer original solutions. Such garments are forced to use more rigid materials since only these can survive extreme environments. Exotic techniques developed in garments made for extreme conditions include: stove pipe joints for underwater hard suits (figure 22, below) and constant volume bellows for space suits (figure 23) (Watkins 1995 pp. 262 - 263). Sportswear in turn offers exotic methods for increasing mobility such as shingling (figure 24) or segmented padding (see figure 25) (Watkins 1995, pp. 122 - 126). There are also times when social convention demands that only non-stretch materials can be used, such as in suits and formal wear. For example, we do not expect formal or business wear to offer the same mobility as casual or sportswear (Ashdown 2011, p. 278). Despite rapid advances in hi-tech flexible materials, we may conclude that the restrictions of extreme environments and social conventions will mean there is still a need for patternmaking techniques that can manipulate garments made from non-stretch materials.

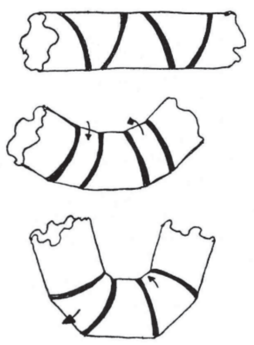


Figure 22: A stove-pipe joint for rigid materials. The sections are joined with ring bearings and rotated by body movement (Radnofsky 1967, cited in Watkins 1995, p. 262).

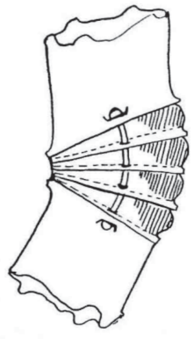


Figure 23: "A constant-volume joint using rigid and flexible materials" (Radnofsky 1967, cited in Watkins 1995, p. 262).

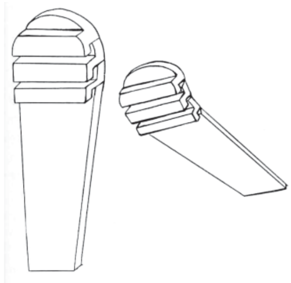


Figure 24: A segmented knee/shin protector which uses a shingling design giving flexiblility to rigid materials (Watkins 1995, p. 124).

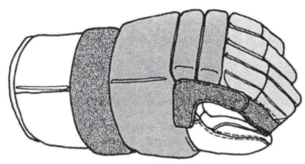


Figure 25: A glove that uses segmented padding (Watkins 1995, p. 124).

Reliance on flexible materials to solve fitting problems

There is a common perception that material with flexible or stretch properties reduces the need for accurate patternmaking. "Stretch fabrics are increasingly being used across the whole gamut of clothing applications fashion sportswear, medical, intimate body wear and technical garments" (Watkins 2011, p. 262). Many hi-tech materials have flexible properties, and this offers many advantages. One distinctive feature of patternmaking with stretch materials is the concept of "negative ease" (Watkins 2011, p. 262), where a stretch garment is designed to be smaller than the body and will stretch to the size of the wearer. This is the opposite of "ease", where the garment is larger than the body. Although flexible materials have a greater ability to fit a wider variety of sizes, a garment's capacity to stretch on the body does not guarantee it will create a comfortable fit.

Patternmakers play a critical role in the highly subjective process of determining the fitting of a stretch garment. According to Watkins "Fit related to the holding power of a stretch fabric in developing the pattern profile geometry is, to date, dependent on subjective expertise" (2011, p. 245). Shoben suggests that "pattern cutting is an art not a science, and that dealing with stretch fabrics is a minefield because the almost unlimited variations in their composition make the question of pattern size difficult" (2008, cited in Watkins 2011, p. 262). This means the role of the patternmaker is still critical in the patternmaking process and cannot be circumvented by simply using stretch materials.

Limitations of "anti-fit" garments

"Anti-Fit" garments attempt to fit the body in a non-conventional way to avoid traditional tailoring techniques. There are many strategies for using anti-fit garments on the body. Some garments incorporate excessive material in the clothing and have a loose non-tailored fit (figure 26, below). Other garments are entirely made of stretch materials and rely on the material to "deform" to the shape of the body (figure 27). There are also garments that use multiple pleats to give flexible properties (figure 28). These ideas offer novel solutions but are not always able to solve the dilemma of fitting clothing comfortably around the body.

Figure 26: A kimono. A garment which is larger than the body and is fastened at the waist for a closer fit (Milenovich 2007, p. 37).

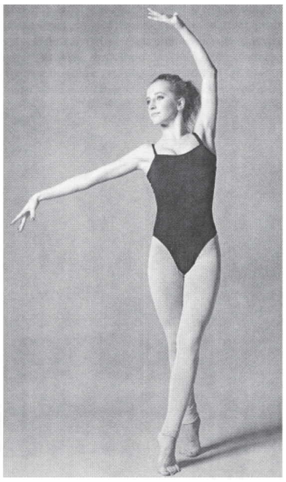


Figure 27: A stretch garment (Ashdown 2011, p. 284).

Figure 28: An Issey Miyake "Pleat Please" dress. A garment which is accordion-pleated and can stretch to fit the body (Béhaïm 1997, p. 61).

Due to fashion's strong social conventions, anti-fit garments often are not as versatile as fitted garments, in that they are limited to a narrower range of social situations. This is because anti-fit garments create their own set of aesthetics and social conventions. Tailoring is widely used to show off the wearer through the skill of the tailoring, and there are many garments that cannot be fitted without tailoring techniques. Anti-fit garments create their own aesthetic and are often only appropriate for a limited set of social circumstances. For example, if one attended a business meeting it would be socially acceptable to wear a suit, yet if one arrived wearing a kimono, a spandex bodysuit, a poncho or a Pleats Please shirt, it may not be so acceptable.

New technologies need new scientific methodologies

The emergence of new technologies has led to an interest in developing new scientific methodologies for fitting clothing. These new techniques are aimed at turning the tacit (subjective) experiences of a patternmaker into a rigorous and objective system which can work with computer-aided design and three-dimensional scanners. Watkins describes how traditional patternmaking techniques are limited by the technology of their time and are now inappropriate for use with modern technology (2011, p. 245). It is time, he says, to re-examine the theories behind fitting methodologies so that they can be re-interpreted to work with emerging technologies.

Yu describes how traditional manual methods of body measurement have so many limitations that many clothing researchers see the need to initiate clothing measurement surveys using three-dimensional scanners (Yu 2004, p. 193). Huang et al. however, identify faults in many existing computer algorithms which convert three-dimensional scans into flat patterns (2012, pp. 680 - 683). Chen concurs on the inaccuracy of such CAD systems and states just how valuable a reliable 3D system would be (1998, ch. 3 p. 4). All these commentators identify the need to develop accurate algorithms that can work with 3D scans and suggest that they would have great commercial applications.

New technologies have also led technologists to seek to apply new knowledge to traditional techniques. Watkins describes how there have been great advances in the measurement of body movement, yet advances in clothing design have come at a much slower pace (2011, p. 240). Further, new methodologies do not just affect traditional tailored non-stretch garments. Watkins describes the subjective nature of working with stretch materials and how a more objective process would be beneficial. He states:

> "It is imperative that the designer uses a mathematical method for quantifying the degree of fabric stretch to be applied in the pattern reduction process. The making of this tacit knowledge explicit will improve communication between industry, science, technology and practitioners to further develop emerging digital technologies in compressive stretch garment design" (Watkins 2011, p. 262).

In essence, it is the emphasis on trying to turn what is considered as "experience" into objective and methodical processes, that drives fashion technologists.

Limitations of 3D scanners

Three-dimensional scanners are an emerging technology with the potential to solve many traditional fitting problems.

> "One significant advantage of most 3D body scanners is the rapid scanning time and more accurate reproducible measurements. This machine generates an unlimited number of linear and non-linear measurements of the human body in just a few seconds" (Yu 2004, p. 135).

Yet while it may appear that three-dimensional scanners can solve all our fitting problems, they still have limitations. Watkins tells us:

> "Although 3D design using virtual mannequins is exciting lots of media attention, there are significant problems in reverse engineering the pattern pieces into real world garments. Virtual fit is problematic as variables are introduced at each stage of the pattern production process" (2011, p. 245).

Indeed, many challenges arise at each step of garment construction from three-dimensional scanners. Bond states that "one major problem with virtual fit technology is the ability to predict size and fit accurately" (2008, pp. 152 - 153). He views current 3D scanning techniques as more of a marketing tool, and that the technology still requires deeper research. In fact there are many experts who are critical of the application of 3D scanning algorithms. Fashion technologists are critical of specific limitations in existing scanning technology. Most body scanners have difficulty scanning the entire body and this leaves hidden areas which cannot be measured. Yu describes how "the armpits, the crotch and the areas under the bust and chin are often shaded. This causes problems with missing data" (2004, p. 165). Further, Istook mentions how a scan cannot see "the top of the shoulders, the bottom of the feet, the crotch at the junction of the legs, and the armpits" (2008, p. 105). He describes how some programs approximate the shape of the body using "averaged" data when body parts are not visible. Such approximations lead to inaccurate measurements. Istook is also critical of how foundational garments worn while being scanned can distort the overall measurements of a scanner (2008, p. 105). If foundational garments are too tight or loose they can easily distort measurements of the scan. Foundational garments also tend to dramatically re-shape the female form and alter posture. These can create fitting problems later on.

Three-dimensional scanners also display inconsistencies when taking "accurate" measurements of the body. The manner in which a 3D scan interprets 3D data into body measurements is of great importance. Simmons and Istook are critical of the variance of data as a result of how each scanner captures or extracts different body measurements (2003, cited in Istook 2008, p. 106). Some scanners try to identify body landmarks - a process that is subjective even for patternmakers, so it is not surprising that computer programs encounter difficulties. To identify a body landmark there has to be a degree of intelligence programmed into an algorithm, whereby the algorithm must make judgements and decisions in order to analyse the scan and identify landmarks. In short, computer algorithms encounter similar problems to humans when trying to interpret 3D data into a flat pattern.

Some experts are critical of how many 3D algorithms, tending to ignore patternmaking techniques, use mathematical principles for flattening a 3D shape and create unusable patterns. Huang et al. identify that many computer algorithms create patterns that are impractical to manufacture and completely neglect basic considerations such as "ease" (2012, pp. 680 - 683). Chen describes how:

> "Academic research in 3D pattern design concentrates mainly on mathematical calculation or computerisation which has ignored manual cutting expertise. Having realised this, it is seen as crucial that a different approach to this modern 3D technology will need to take account of the knowledge of garment pattern cutting expertise. This would need the selection of one leading system for the experiments" (1998, ch. 3 p. 78).

In describing how such techniques are overly reliant on mathematical theories and fail to consider the craft of patternmaking, Watkins adds:

> "Most CAD software systems are based on computerised versions of traditional empirical haptic methods that have emerged through trial and error and, more often than not, manual intervention is needed to produce a good custom fit" (2011, p. 246).

Herein is the same problem encountered by traditional patternmaking techniques that rely on the patternmaker and his trial-and-error fittings. Chen states that:

> “Only by understanding the problems as perceived by an expert pattern cutter can the 3D-2D flattening process be improved, or at least necessary improvements specified” (1998 ch. 3 p. 78).

Fashion technologists in general tend to underestimate the intelligence required to interpret three-dimensional data into a flat pattern. 3D scanners are tools for measuring the body, and few consider that the algorithm that interprets that data should have the same intelligence as a patternmaker. Kwong describes how:

> “Experienced pattern makers have developed a set of heuristics that enable them to make pattern changes rapidly. Nevertheless, computer systems do not have the “experience” or background knowledge which experienced pattern makers have to accomplish rapid alterations” (2004, p. 202).

And:

> “Although CAD systems cannot learn by experience, once the heuristics have been developed within a CAD system, it can process the information and perform the functions more rapidly, accurately and consistently than the most experienced pattern maker” (Kwong 2004, p. 202).

The difficulty with this notion is that it is incredibly difficult to distil the experience of a patternmaker into a single “heuristic” algorithm. An experienced patternmaker possesses the intelligence to solve problems, make judgements, recognise patterns and make aesthetic decisions at an immensely sophisticated level. To replicate this experience would require artificial intelligence as sophisticated as the mind of the patternmaker. The upshot is, that to develop a patternmaking system that is more accurate and less reliant on subjective skills, will only decrease the intelligence required from the patternmaker.

Three-dimensional scanners also tend to exacerbate our problems with lack of standardisation in anthropometric systems. There are no universal standards for clothing, and anthropometric protocols for 3D scanners are still in their infancy. The closest we have to an international standard are the American Society for Testing and Materials (ASTM) and the International Organization Standardization (ISO). These systems have strict injunctions on how to take physical measurements.

Istook states:

> "…There are currently no published standards on the interpretation of measurements obtained from 3D scanned images. Standards for body and garment dimensions have been developed by ASTM in the US and ISO in Europe. Three-dimensional body scanning brings to the forefront issues concerning these current standards" (2008, p. 106).

Istook describes how the measuring protocols of non-contact 3D scan measurements are incompatible with traditional measurement systems, and how many of these standards require physical contact, such as bending body parts to identify the appropriate body landmarks. He suggests:

> "New standards are needed that will work for 3D scanners globally and both ISO and ASTM are currently working on establishing standards that will enable a common understanding among and between scanners and conventional measuring methods" (2008, p. 106).

Deficiencies in existing patternmaking systems are in fact emphasized by three-dimensional scanning software. For example, 3D scanners are limited in the way that they can only capture the body for an instant. Yu describes how:

> "The human body is constantly changing, even when standing still. Movement due to swaying, breathing and posture changes during scanning can readily affect measurements, such as the chest circumference" (2004, p. 165).

While modern advances in scanning technology show just how dynamic the human body is, patternmaking can still only analyse static patterns which capture the shape of the body for an instant. A study such as Atkin's experiment of cutting slits into garments (see Figure 19) demonstrates how a pattern changes with movement (1980, cited in Watkins 1995, p. 241). Every breath, piece of food consumed or subtle shift in posture will change the shape of the body and consequently the pattern. 3D scanners can help record each instant of this process, but patternmaking still struggles to fully understand the total movement of the body. Any patternmaking system that can record and analyse this movement would be a paradigm shift in improving current patternmaking systems.

CHAPTER 3

Insights from Non-Euclidean Geometry

The Significance of Non-Euclidean geometry in fashion patternmaking

Non-Euclidean geometry offers a new way to explain many of fashion patternmaking's fundamental problems. Introducing new geometric concepts to fashion patternmaking, it lets us describe curved surfaces with much greater precision. The application of mathematics to fashion patternmaking allows traditional techniques to be explained using logical reasoning and mathematical rigor. Non-Euclidean geometry can explain and solve many of fashion patternmaking's limitations and problems. Hereby, we empower the patternmaker, who, instead of relying on tradition and anecdotal evidence, can use geometry to explain how traditional processes work.

The mathematics of Non-Euclidean geometry presents a steep learning curve, especially for fashion designers. Initial concepts are easy to learn, but to follow the mathematics on a deeper level becomes much more challenging. Fortunately, there are extremely informative books, such as mathematician Roger Penrose's *Road to Reality* (2004) and Week's *The Shape of Space* (2002). These works assume no prior knowledge of mathematics and explain processes from first principles. Further, the work of Taimina is useful, presenting mathematical concepts visually and demonstrates how these ideas can be applied to crochet. Mlodinow's *Euclid's Window* (2001) explains the technological significance of diverse geometric discoveries throughout history. Mathematical works by Tabak (2011), Vince

(2005), Trudeau (1987) and Jennings (1994) also help to explain the history and applications of Non-Euclidean geometry.

Non-Euclidean geometry expounds concepts that can explain curved surfaces, yet it is a challenge to find applications that translate directly from mathematics to fashion patternmaking. Mathematics is written to satisfy the needs of mathematicians, and is often written for idealised scenarios which may not have real-world applications. To calculate the properties of curved shapes we need to know the equation of their forms. It is easy to make calculations on idealised shapes such as a sphere; however, making calculations on the curved shape of the human body becomes extremely complex. The messiness of the real world makes applying these clever geometric ideas impractical. Mathematicians often try to use computer software to handle complex calculations, yet patternmaking and draping fabric on the body is a tactile experience. Taking the patternmaker away from the mannequin would forfeit an entire dimension of the process. The solution is to find a form of mathematics that has the rigour of Non-Euclidean geometry, while still being simple enough for fashion designers to use.

We must accept though, that mathematics can be deeply intimidating to fashion patternmakers, throwing many of them out of their comfort zone. Our research in this thesis introduces basic mathematical concepts such as calculus, limits and transcendental numbers. In order to transfer this knowledge to patternmakers we have endeavoured to explain complex mathematical concepts visually, using diagrams. Our goal is to distil the essence of these ideas and communicate them to fashion industry professionals with little prior knowledge of mathematics.

Introduction to Non-Euclidean geometry

Non-Euclidean geometry is a form of mathematics that can describe three-dimensional curved surfaces. It emerged in the 19^{th} century and is a relatively recent discovery in mathematics. At the time it was proposed, Non-Euclidean geometry was considered to be absurd by many experts in the mathematical community (Tabak 2004, p. 88). This revolutionary idea ran counter to the established view of Euclidean geometry that was unchallenged for thousands of years. Euclidean geometry is a self-consistent set of rules that govern the mathematics of flat surfaces. Non-Euclidean Geometry posits a different set of self-consistent rules that describe curved surfaces, such as those which are spherical (spherical geometry) and saddle-shaped (hyperbolic geometry) (see figure 1, below). Curved surfaces require an entirely different paradigm, and different geometric rules. Everything about Non-Euclidean geometry is counter-intuitive in relation to the paradigm of Euclidean geometry. Nevertheless, Non-Euclidean geometry has now become commonplace in science, mathematics and engineering.

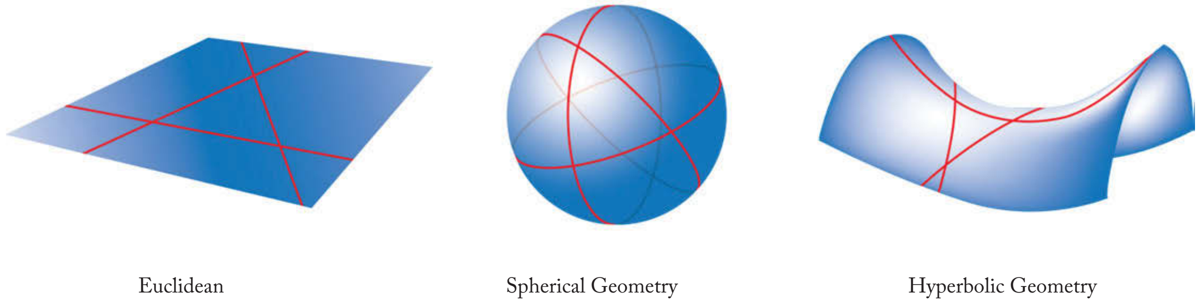


Figure 1: Euclidean Geometry in relation to Non-Euclidean Geometry.

Euclidean geometry

Clearly, in order to understand Non-Euclidean geometry we must first understand Euclidean geometry. The latter was established by ancient Greek mathematicians, notably Thales, around 600 BCE (Trudeau 1987, p. 1). At this time the Egyptians and Babylonians had the concept of "earth measurement" for which the Greek word is "geometry" (Mlodinow 2001, p. 3). Before Thales the term geometry had meant "surveying" and amounted to a practical way to measure objects such as fields (Trudeau 1987, p. 1). Such methods of surveying are inaccurate and subjective, and highly dependent on the skill and experience of the measurer. Thales introduced a systemisation of geometry whereby instead of measuring physical objects he assessed the properties of abstract shapes (Mlodinow, 2001 p. 14). This allowed him to examine "the hodgepodge of geometric recipes, rules of thumb, and empirical formulae that have been transmitted from Babylonia and Egypt, to detect an order" (Trudeau 1987, p. 1). From this, Thales noted that some geometric facts are deducible from others and that geometry could be worked out mentally. This was a major discovery for mathematics, as geometry moved away from being a craft for surveying objects into a set of established geometric rules.

The discovery of "abstraction" enabled mathematicians, notably Pythagoras, to turn geometry into a deductive science (Trudeau 1987, p. 4). This established many of the conventions of the mathematical proof and theorem. While the process of deduction established theorems based on logical reasoning, in mathematics logic must still be based on assumptions. These, called "axioms" are principles on which proofs are built. "Axioms" are accepted to be true yet are often without proof. The convention of defining terms and formulating theorems from logic alone led to what modern mathematicians term "rigour" (Trudeau 1987, p. 4). Before the 5th century BCE mathematics is thereby seen as not "rigorous" (Trudeau 1987, p. 4) but beyond it, "rigour" becomes a standard in mathematics.

The "rigorization" of mathematics would continue in the ancient world, and is embodied in Euclid's book *Elements.* This work contains 465 theorems compiled around 300 BCE (Trudeau 1987, p. 5). "Euclid attempted to axiomatize - that is, he tried to establish a logically consistent and complete set of "rules" from which the entire subject of Euclidean geometry could be deduced" (Tabak 2004, p. 28). These rules or "postulates" would allow modern trigonometry to deduce all sorts of mathematical relationships between different shapes. These would become powerful tools for mathematics, science and engineering - rules so essential that they are taught in high school trigonometry. Students will be familiar with principles such as the interior angles of a triangle equalling 180 degrees (see figure 2, below). Another key concept is the working out of similar angles when a line crosses a pair of parallel lines (figure 3). Again, Euclid's fifth postulate or "parallel postulate" established rules for parallel lines (see figures 4 and 5). This postulate can be used to deduce the properties of the angles of a line that crosses two parallel lines (see figure 3).

Figure 2: A physical demonstration of how a triangle has a total of 180 degrees (Taimina 2009, p. 29).

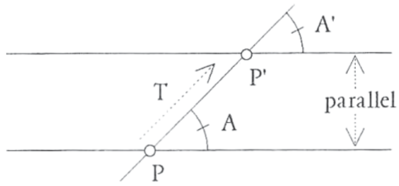
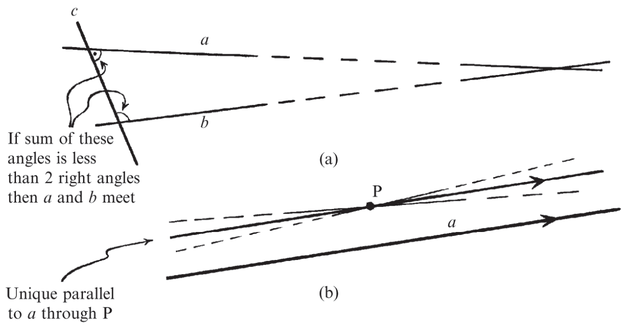
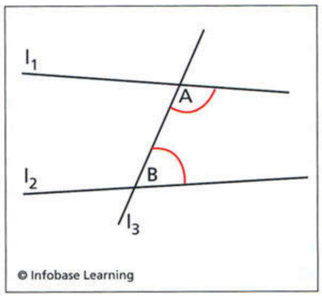


Figure 3: The two angles A and A′ are equal, due to the properties of parallel lines (Jennings 1994, p. 18).



(a) Euclid's parallel postulate. Lines *a* and *b* are transversals to a third line *c*, such that the interior angles where *a* and *b* meet *c* add to less than two right angles. Then *a* and *b* (assumed extended far enough) will ultimately intersect each other. (b) Playfair's (equivalent) axiom: if *a* is a line in a plane and P a point of the plane not on *a*, then there is just one line parallel to *a* through P, in the plane.

Figure 4: Euclid's Fifth Postulate and Playfair's Axiom (Penrose 2004, p. 30).

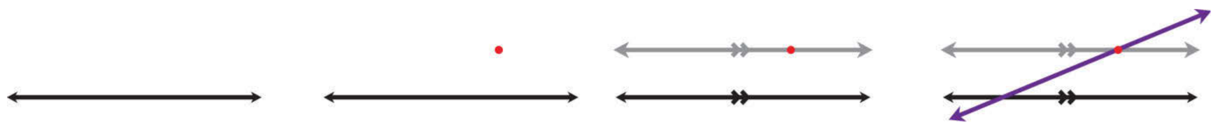


The fifth postulate states that if the sum of the measures of angles A *and* B *is less than 180°, then lines* l_1 *and* l_2 *intersect on the same side of* l_3 *as* A *and* B.

Figure 5: Euclid's Fifth Postulate (Tabak 2004, p. 29).

The principles of Euclid were very much entrenched in mathematical thought until the early 18th century. Of all the theorems in Euclidean geometry, Euclid's Fifth or "parallel postulate" was seen as the weakest, and was challenged by many mathematicians. While it seemed self-evident, there was no rigorous mathematical proof to justify it. In the 18th century Scottish mathematician John Playfair published Playfair's postulate, a simplified version of the parallel postulate (Stillwell 2005, p. 22). This gained popularity and replaced the parallel postulate.

Playfair's postulate asserts: "For any straight line and for any point not on the line, there is a unique straight line through the point which is parallel to the line" (Penrose 2004, p. 29). (See figure 4). This concept is demonstrated in figure 6 below. This thesis will use Playfair's Axiom to describe the parallel postulate, as it is simpler and makes explaining the geometry easier. So, for hundreds of years this principle could be demonstrated and seemed self-evident. It works with flat surfaces, but what happens when parallel lines are drawn on curved surfaces?



Draw a line

Find a point not on the line.

We can only draw one unique parallel line which passes through the point and is parallel to the original line.

Besides the one unique parallel line, any other line that passes though the point is not parallel.

Figure 6: A demonstration of Playfair's Axiom.

The Non-Euclidean revolution

Dissatisfaction with the parallel postulate led to the development of a new form of geometry. "The person who is first scorned and later celebrated for making a radical break with the past is the Russian mathematician Nikolai Ivanovich Lobachevsky" (Tabak 2004, p. 88). Lobachevski was fascinated with Euclid's fifth postulate and was seeking a rigorous proof for it (Tabak 2004, p. 90). In fact, since

Euclid, hundreds of years were spent on failed proofs for the parallel postulate. By the end of the 18th century many mathematicians began to conclude that the parallel postulate could not be proved as a consequence of Euclid's other postulates, instead constituting a stand-alone idea (Tabak 2004, p. 90). Grasping the problems with Euclid's parallel postulate, Lobachevsky developed his own alternative. Under Euclid, given a straight line and a point not on the line, only one parallel line could pass through that point (see figure 7, below). Lobachevsky's modified postulate allowed two distinct parallel lines to pass through this point while still being parallel to the original line. While this may not seem to make any sense on a flat surface, the crucial implication of Lobachevsky's postulate is that he started doing geometry on curved surfaces (see figure 8). Lobachevsky realized that he could develop a logically-consistent set of rules for a new geometry that diverged from the axioms and postulates of Euclid (see figure 9) (Tabak 2004, p. 92). For example, in Lobachevsky's new "Non-Euclidean" geometry the sum of the interior angles of a triangle can be less than 180 degrees - compared to Euclidean geometry where the sum of the angles is always 180 degrees (see figure 10). Lobachevsky had in fact discovered a way of describing the geometry of curved surfaces (see figure 8). These discoveries were at first met with fierce controversy, seeming to violate all the rules of Euclidean geometry while still being logically consistent. In sum, they established an alternative: the "Non-Euclidean" system.

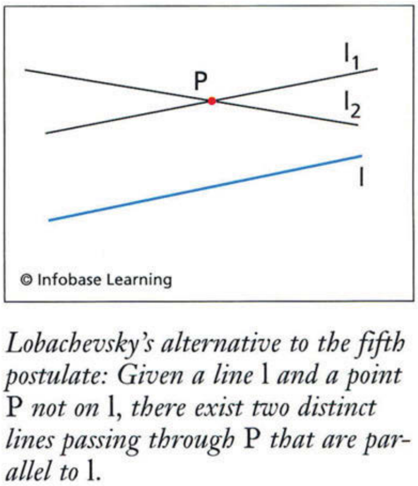


Figure 7: Lobachevsky found scenarios where there could be more than one parallel line passing through a single point (Tabak 2004, p. 91).

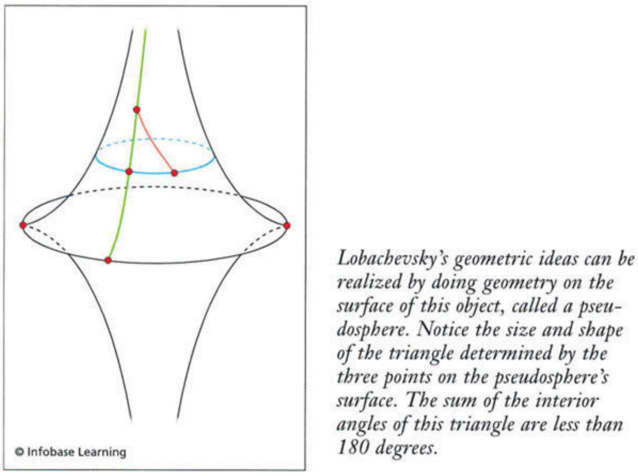
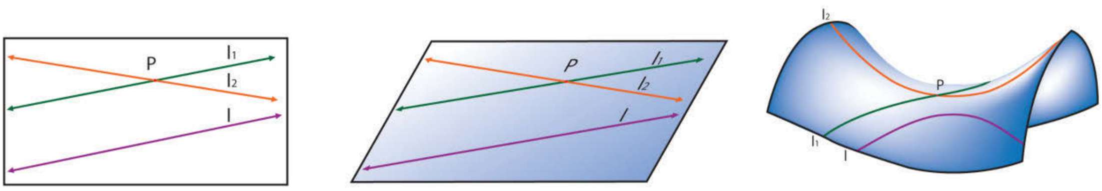


Figure 8: The implication of Lobachevsky's alternative to the parallel postulate is that he discovered he was doing geometry on curved three-dimensional surfaces (Tabak 2004, p. 92).

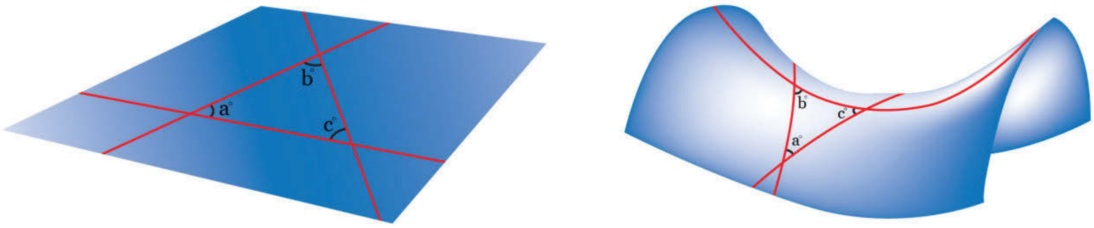


Lobachevsky's alternative to Euclid's fifth postulate: Given a line 1 and a point P not on 1, there exists two distinct lines passing through P that are parallel to 1.

It is not possible to have more than one parallel point pass through a point on a flat surface.

It is possible to have more than one parallel line pass through a point on a curved hyperbolic surface.

Figure 9: Lobachevsky found that more than one parallel line could pass through a single point on a curved surface.



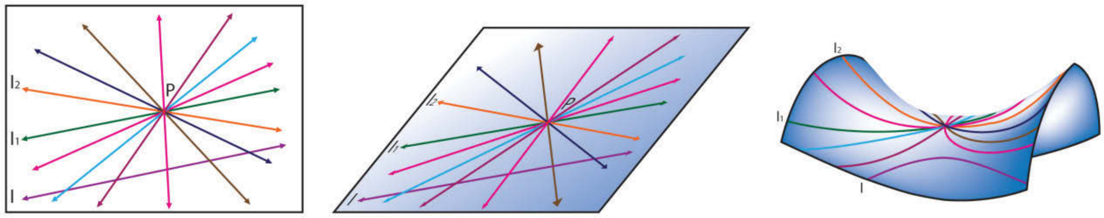
Flat Euclidean surface: $a° + b° + c° = 180°$ Hyperbolic surface: $a° + b° + c° < 180°$

Figure 10:

On a flat Euclidean surface the total angles of a triangle equal 180 degrees.

On a hyperbolic surface the total angles in a triangle are less than 180 degrees.

Lobachevsky, while the first to publish his findings, was not the only mathematician developing Non-Euclidean geometry. Hungarian mathematician Janos Bolyai simply replaced the parallel postulate with a version of his own which posits a line and a point with an infinite amount of parallel lines passing through that point (see figure 11, below) (Tabak 2004, p. 95). His technique is similar to Lobachevsky's but not identical. Bolyai realised the implications of his discovery and famously wrote to his father Farkas Bolyai (also an established mathematician) saying: "I created a new, different world out of nothing" (Dénes 2011, p. 41). Bolyai's father in turn corresponded with the prominent mathematician Carl Friedrich Gauss. On hearing about Janos' discovery, Gauss praised him on the genius of it, but also mentioned that he had been developing work of his own in the field. Gauss himself would go on to develop a vast body of research on the curvature on Non-Euclidean surfaces.



Bolyai's alternative to Euclid's fifth postulate: Given a line 1 and a point P not on 1, there are unlimited distinct lines passing through P that are parallel to 1.

It is not possible to have an unlimited number of parallel lines pass through a point on a flat surface.

It is possible to have an unlimited number of parallel lines pass through a point on a curved hyperbolic surface.

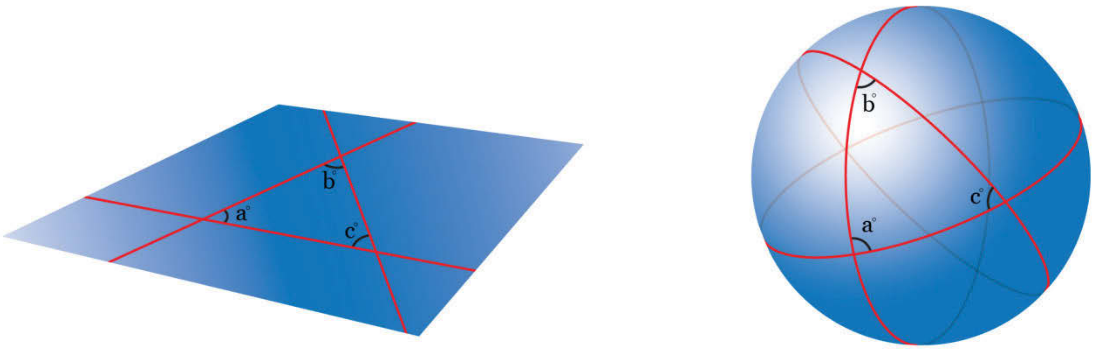
Figure 11: Bolyai found that an infinite number of parallel lines could pass through a single point on a curved surface.

The Non-Euclidean revolution by these pioneers of the 18th century led mathematicians to completely re-evaluate their subject. The discoveries of Lobachevsky, Bolyai and Gauss became known as "Bolyai-Lobachevsky" geometry or "hyperbolic" geometry. This geometry described the shape of saddle-shaped surfaces, wherein the interior angles of a triangle have a sum of less than 180 degrees (see figure 10). Given a straight line and a point there is an infinite number of parallel lines that run though that point that are still parallel to the straight line (see figure 11). Hyperbolic surfaces also have their own trigonometric rules; further, the rules of Euclidean geometry do not work on non-Euclidean surfaces. These properties may have seemed strange and unthinkable to ancient Greek mathematicians, yet there is another form of non-Euclidean geometry which Greek mathematicians had experienced but not fully explored.

"Spherical" geometry is another form of non-Euclidean geometry that relates to spherical surfaces. Ancient civilizations including the Greeks, Egyptians and Babylonians were very much attuned to working with spherical shapes, which were used in a very practical manner for astronomy and navigation around the spherical shape of the Earth (Henderson & Taimina 2005, pp. 25 - 28). The ancient Babylonians developed a system of spherical coordinates (Henderson & Taimina 2005, pp. 25 - 26) similar to our modern-day longitude and latitude. The first systematic account of spherical geometry is *Sphaerica* by Theodosius, written around 200 BCE (Henderson & Taimina 2005, p. 28). Ptolemy's book *Mathematiki Syntaxis* or Mathematical Collections, which included discoveries in spherical geometry, became a cornerstone of Western mathematics for the next 1400 years (Henderson & Taimina 2005, p. 28). In the 19th century, mathematicians such as Bernhard Riemann would develop this geometry into what is called Riemannian or Elliptical geometry.

Modern Non-Euclidean geometry

Modern spherical geometry contains very different rules and properties to Euclidean geometry. On a sphere the interior angles of a triangle will total a sum greater than 180 degrees (see figure 12, below). This is due to the curvature of the surface and the size of the sphere, in that a small sphere will have a high curvature while a very large sphere will have a flatter surface. We can experience this principle, since the Earth as a giant sphere has a radius so large and a curvature so low, that the land seems flat. In contrast, a marble has a small radius and high curvature, appearing curved. This relationship between curvature and surface is worked out by Gauss and is determined by the radius of the sphere. In spherical geometry curvature is proportional to the inverse of the radius (see figure 13). In spherical geometry this curvature is a positive number and is called "positive curvature". The principle of curvature can also be applied to hyperbolic geometry, but in a slightly different way: hyperbolic shapes have "negative curvature" in that the radius of their curvature is measured by the radius of the sphere as measured outside the surface (see figure 14).



Flat Euclidean surface: $a° + b° + c° = 180°$ Spherical surface: $a° + b° + c° > 180°$

Figure 12: On a spherical surface, the total angles in a triangle are greater than 180 degrees.

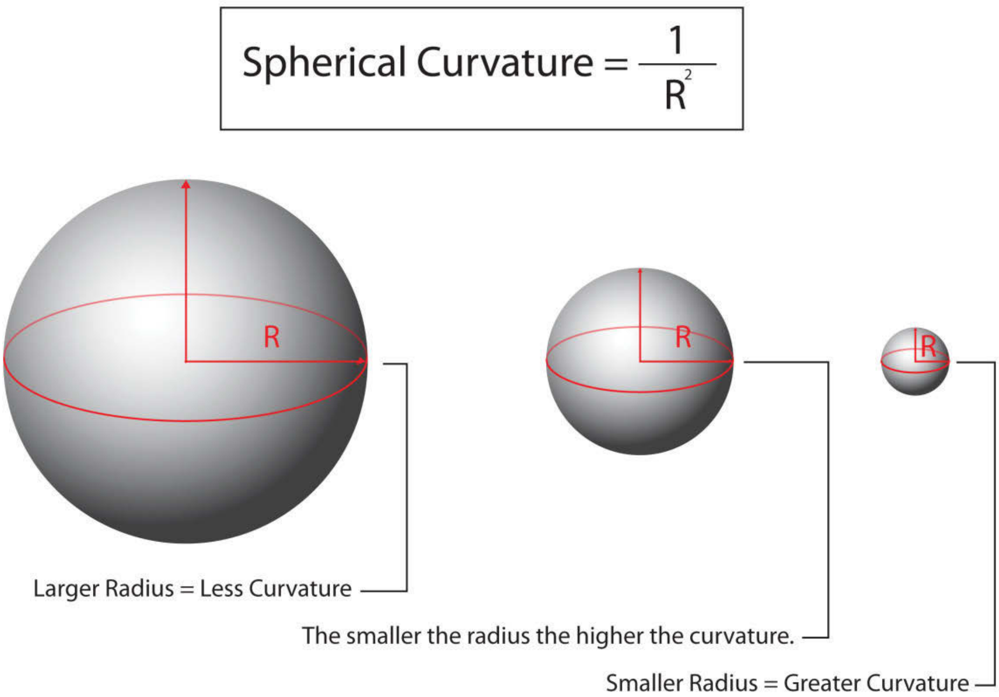


Figure 13: The curvature of Spherical Geometry.

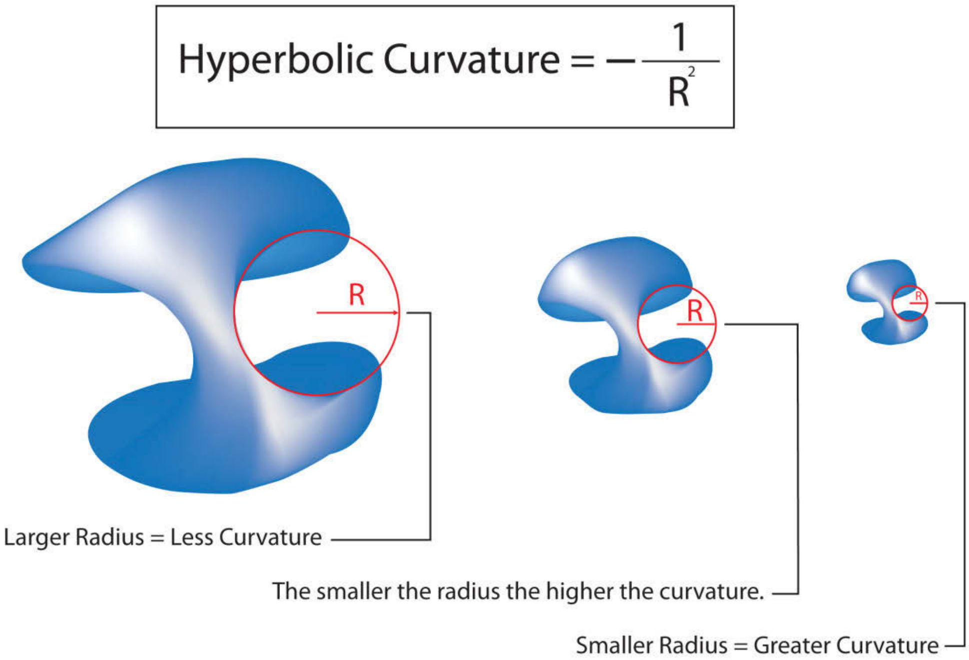
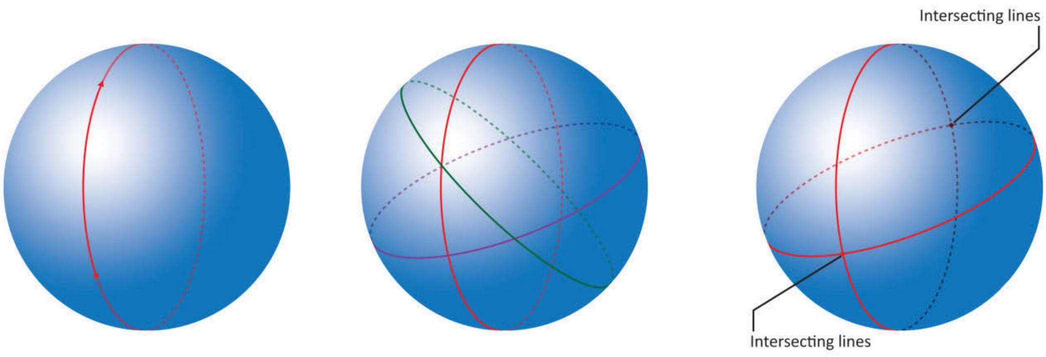


Figure 14: The curvature of Hyperbolic Geometry: hyperbolic shapes have negative curvature.

The parallel postulate also works in a very different way on a sphere. If we draw a straight line on a sphere, the result is a circle. This circle's length is in fact the maximum circumference of the sphere, and is called a "great circle". When we draw two parallel lines on a sphere they become great circles and will always intersect twice (see figure 15, below). For this reason, in spherical geometry there can be no parallel lines on a sphere. This leads us to challenge the very notion of what a straight line on a curved surface actually is. In Non-Euclidean geometry the concept of the "geodesic" is introduced. A geodesic is the shortest distance between two points on a curved surface (see figure 16). Spherical and elliptical geometry have this property, and can be used to describe curved surfaces.

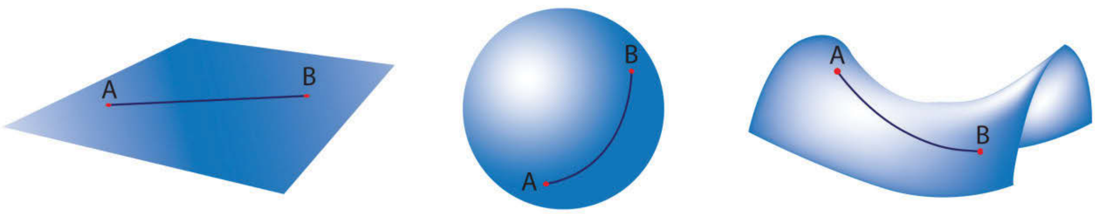


If we draw a continuous line on a sphere it becomes a circle. This circle covers the maximum circumference of the sphere and is called a "great circle".

Examples of "great circles".

To draw any two great circles on a sphere makes them intersect twice. It is thereby not possible to have parallel lines on a sphere. This explains why there are no parallel lines in spherical geometry.

Figure 15: There are no parallel lines in spherical geometry.



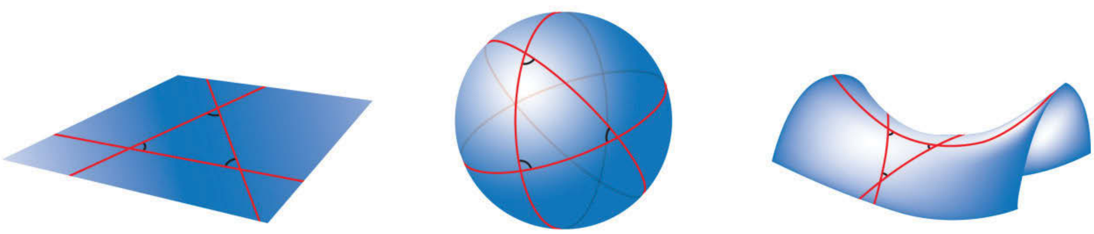
A Geodesic on a Euclidean plane.

A Geodesic on a sphere.

A Geodesic on a hyperbolic surface.

Figure 16: A Geodesic is the shortest distance between two points on a curved surface.

As can be seen in figure 17 (below), Euclidean, Spherical and Hyperbolic geometry have very different properties.



Euclidean Geometry

Spherical Geometry

Hyperbolic Geometry

Figure 17: The properties of different types of geometry.

While we offer here a very brief overview of Non-Euclidean geometry, we claim to introduce many of the ideas that are practically applicable to fashion pattern cutting.

Non-Euclidean geometry in popular culture

Even though non-Euclidean geometry has been accepted by the modern mathematical community, it is still perceived as strange and counter-intuitive by popular culture. Thurston asserts that "Non-Euclidean or hyperbolic geometry is a topic of great mystery and confusion for many centuries" (Taimina 2009 p. ix). In the art world, the works of MC Esher show representations of a hyperbolic plane and evoke a sense of vast complexity (see figures 18 and 19, below). The influential horror writer H P Lovecraft uses the term "Non-Euclidean" to evoke a sense of otherworldly terror in his horror story *Call of Cthulhu* (Lovecraft 2008, p. 222). In fact, Non-Euclidean curved shapes form the majority of shapes in nature, and it is rarer to find idealised Euclidean shapes in nature. In science and engineering Non-Euclidean geometry is a necessity for creating anything with a curved surface.

Figure 18: MC Esher (Taimina 2009, p. 3).

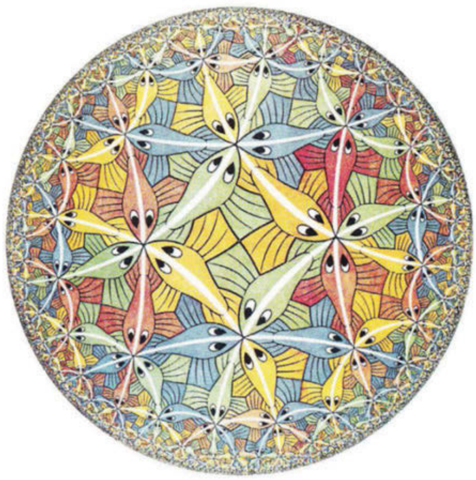


Figure 19: MC Esher (Taimina 2009, p. 16).

In recent years, non-Euclidean geometry has become accessible in new ways. Many findings of mathematicians are technical and intangible due to their lack of real-world applications. Computers allow complex mathematical functions to be visualised as geometric shapes, and nowadays anyone who has seen a modern computer-animated movie by studios such as Pixar have seen visualisations of three-dimensional shapes. These include Non-Euclidean geometry (see figures 20 and 21, below). Mathematicians such as Daina Taimina forged new ground in mathematics and the textile art-form of crochet by creating hyperbolic functions in crochet form (see figure 22 and 23). Taimina is able to use the crochet to turn mathematical functions into tangible and physically manipulable textile forms. This serves to demonstrate complex ideas such as the parallel postulate on a hyperbolic surface (see figures 24 to 26, below). The scientist and journalist Margaret Wertheim and her sister Christine Wertheim extended this idea to create a coral reef out of hyperbolic crochet forms (see figure 27). This artwork demonstrates how scientific principles can be used to physically create, and in this case make a statement on environmental sustainability (Taimina 2009, p. 130). It is inspiring to see how mathematical ideas can be applied to pioneer or enhance developments in the fields of art and design.

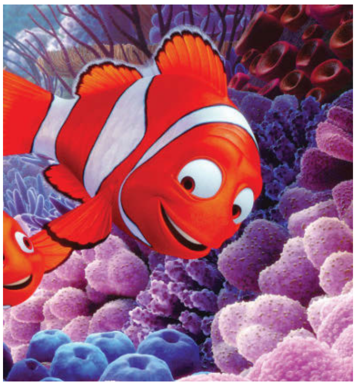


Figure 20: Pixar animations such as *Finding Nemo* are popular in the cinema and are entirely generated using three-dimensional computer animation (Paik 2007, p. 223).

Figure 21: Pixar's computer animation is created by rendering three-dimensional models. These models are created using complex Non-Euclidean geometry (Paik 2007, p. 139).

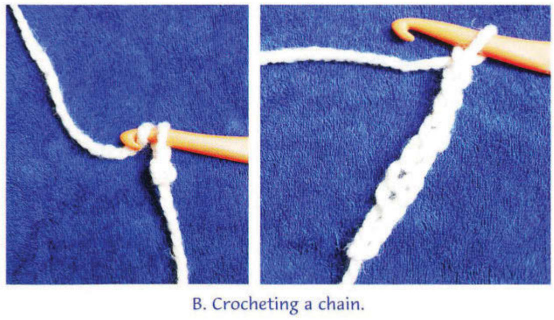
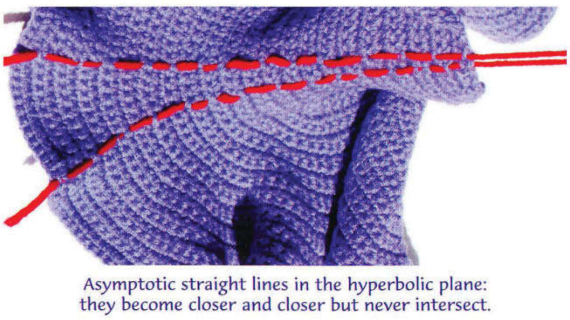


Figure 22: Daina Taimina used traditional craft of crochet to create mathematical models of hyperbolic shapes (Taimina 2009, p. 85).

Figure 23: The traditional craft of crochet allows the construction of hyperbolic forms (Taimina 2009, p. 21).



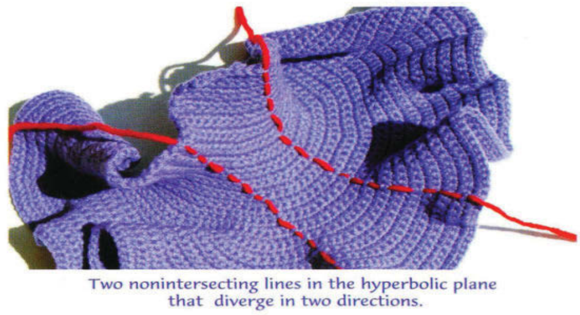


Figure 24: Taimina used crochet models to physically demonstrate principles of hyperbolic geometry (Taimina 2009, p. 27).

Figure 25: A further example of crochet models physically demonstrating principles of hyperbolic geometry (Taimina 2009, p. 27).

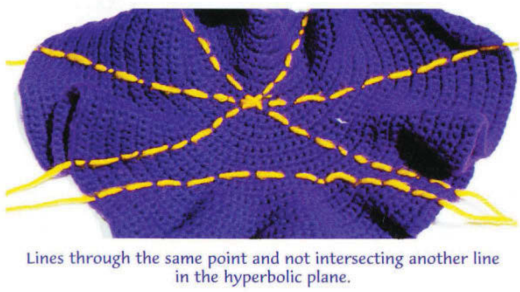


Figure 26: This crochet model demonstrates how a single point on a hyperbolic shape can have an infinite number of parallel lines running through it (Taimina 2009, p. 27).

Figure 27: A coral reef created by crocheting hyperbolic shapes by Margaret Wetheirm and Christine Wetheirm (Taimina 2009, p. 130).

Geometry and the pioneers of traditional fashion patternmaking

In essence, geometry has always been a source of inspiration for fashion designers. Most designers take inspiration from the aesthetics of geometry, but not its function. Far less common are designers who are able to incorporate geometric principles into their designs. Often, this select group will develop new techniques and becoming influential patternmakers. Let us note some examples of designers who have used geometric principles to significantly improve their practise, thereby demonstrating the merits of adapting geometric principles into fashion patternmaking.

Madeline Vionnet, an influential dressmaker and pioneer of numerous patternmaking techniques, constantly explored the geometric shapes of patternmaking and the draped properties of materials. Indeed, she is best known for discovering that cutting cloth on the bias (diagonal to the grain of the cloth) would give it stretch properties (see figure 28, below). Vionnet stated:

> "The couturier should be a geometrician, for the human body makes geometrical figures to which the materials should correspond. If a woman smiles, her dress must also smile" (Kirke 1998, p. 117).

Many of Vionnet's iconic dresses are only possible because of a deep understanding of patternmaking techniques and the properties of fabric (see figure 29). A willingness to explore the underlying geometry of patternmaking and fabric are key to her designs. While in contemporary patternmaking we take these techniques for granted and have built on them, in their time Vionnet's techniques were revolutionary and would have baffled many patternmakers.

Figure 28: A black silk satin and silk crepe dress of Madeleine Vionnet from 1932 (Kirke 1998, p. 89). Madeleine Vionnet is best known for discovering that fabrics draped on the bias have more flexible properties.

Figure 29: A Madeleine Vionnet dress from 1923. It features a bias-cut silk crepe dress from 1923 featuring a carefully-engineered zigzag seam. The skirt is constructed of 6 rectangles of silk (Kirke 1998, p. 57).

Issey Miyake is a contemporary fashion designer who incorporates elements of high technology to push the boundaries of fashion. Miyake often collaborates with scientists to incorporate new technology into his designs. A key example is his *132 5 Collection*, a 2010 collaboration with the mathematician and origami expert Mitani Jun (Fukai *et al.* 2010, pp. 148 - 149). Here, Miyaki's garments are designed with folds built into their structure, then heat-pressed to keep their shape (see figure 30, below). Such sophisticated and unconventional designs are only possible because the garments are designed with a computer folding algorithm. Without the aid of this algorithm and with only traditional practises, these garments would be too complex or time-consuming to develop. Here then is a demonstration of how mathematics, technology and design can combine with spectacular results.

Figure 30: Miyake's *132 5 Collection*, 2010 (Fukai *et al.* 2010, pp. 148 - 149).

Other contemporary fashion designers have also used computer three-dimensional modelling to create stylised 3D garments. These designers use 3D software programs to build forms around the body and then flatten them into flat patterns. Examples of this work include Jensen (figure 31, below), Shaposhnikova (figure 32), Kostowski (figure 33) and Thorarinsdottir (figure 34). These designs all include polygons which stick out of the body. The designers also stiffen the fabric so it is rigid like cardboard or plastic. Yet while these are novel ways to create theatrical garments, their applications are limited, for the reason that it is easy to manipulate simple polygons but much harder to manipulate complex curved surfaces. Certainly, this software can readily create stylised theatrical garments, but using it to engineer a tailored garment is no simple matter.

Figure 31: Anna Marie Skjoldager Jensen, *One Eye Laughing, The Other Eye Crying*. Summer 2009 collection, with work in progress photos (Lee & Shee-reen 2010, pp. 23 - 24).

Figure 32: Irina Shaposhnikova, *Crystallographica*. 2009 collection, with work in progress photos (Lee & Shee-reen 2010, pp. 37 & 41).

Figure 33: Linda Kostowski, *The T-shirt Issue.* 2008 collection, with photos of work in progress (Lee & Shee-reen 2010, p. 87 – 88).

Figure 34: Ninna Thorarinsdottir, *Number Dress 305.* Collection and work in progress photos for *Number Dress 305* and *265* (Lee & Shee-reen 2010, pp. 95 & 97).

Power of geometry to unify traditional systems

There are so many traditional patternmaking systems that it is impractical to analyse them all. Experts such as Kwong, Kunick, Chen and Efrat have analysed many of the prominent systems. Many of these have similarities (see figure 35, below), although each system argues why it makes its distinct choices. Some patternmakers offer versatile systems that allow them to easily communicate with other patternmakers. Indeed, others' systems are usually intertwined as part of an individual's practice, such that it is often difficult to separate the individual from the patternmaking system. This makes finding a common thread that can unify these systems difficult.

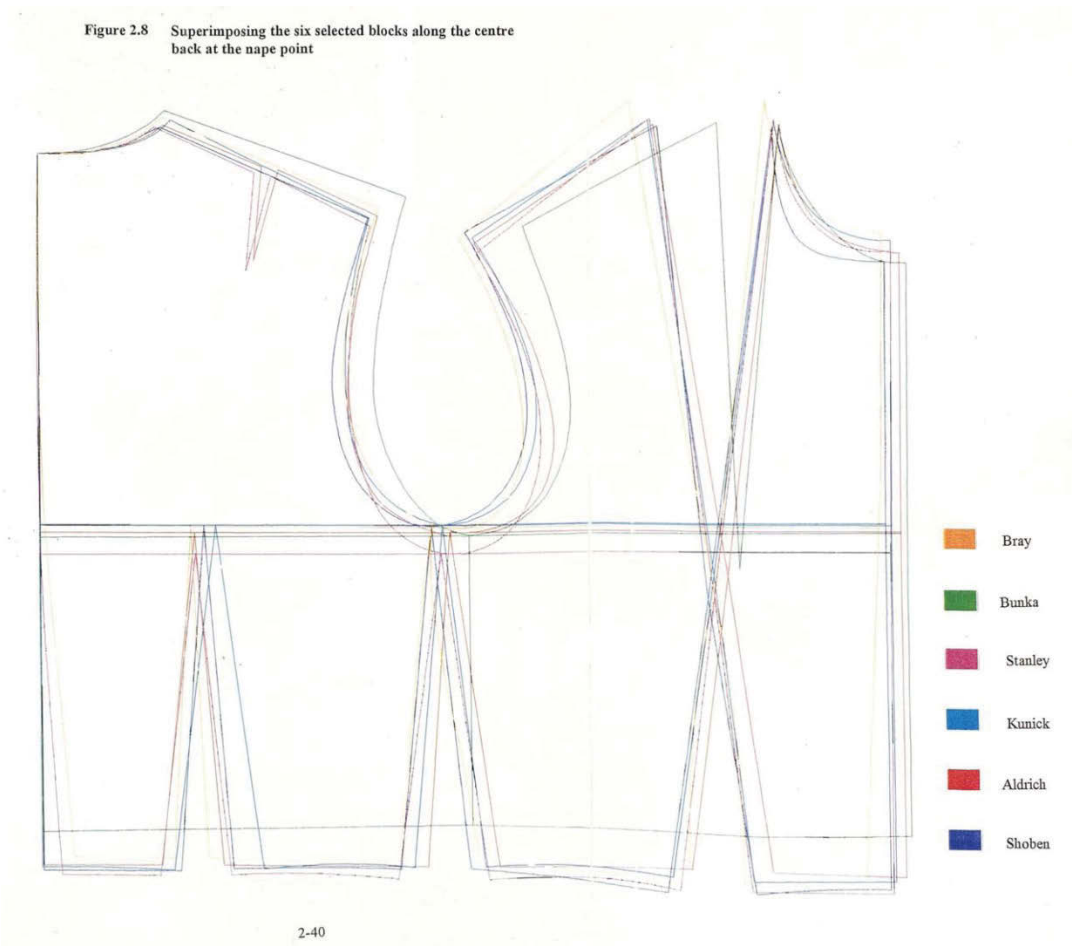


Figure 35: Chen diagram of comparative fashion patternmaking systems (Chen 1998, ch. 2 p. 40).

Analysing patternmaking systems can be difficult as their principles often conflict. Each system professes to be the most effective. In truth, patternmakers become emotionally attached, often arguing the validity of their system based on the skill and reputation of the master they learned from. We can see that it is difficult to argue which system is more effective when the criteria are so subjective. While many systems use common terms and principles, there is no universal definition.

Our research in this thesis argues that it is not important which traditional technique is most effective. What is important is first to understand how these techniques work, and second to develop new techniques which are justifiably effective. While individual techniques should be analysed on their merits to justify their strengths and weaknesses, Non-Euclidean geometry offers mathematical tools to explain how patternmaking principles work, such that the ability to explain how systems work using this geometry has the potential to unify all systems under a universal language. Why? The use of geometry is the one element that all patternmaking systems have in common. All systems incorporate measurements taken from the body that are then drafted into flat patterns. Even practices where patternmakers drape fabric on the body must eventually convert the fabric into a flat pattern. Manipulating darts, fullness and contours are all processes governed by geometry. Though each patternmaking system has its own set of rules, it follows the rules of geometry. In sum, to explain the underlying phenomena of patternmaking in the language of geometry gives insight into all systems.

Drawing on the rich history of mathematics

Applying mathematical rigour to a traditional craft in order to understand it in greater detail has been a successful historical strategy, and Mlodinow argues that it is a process many forms of craft move through in order to gain rapid technological advancement (2001, pp. 4 - 9). One advantage of applying this process in modernity is that we can draw on hundreds of years of mathematical research and knowledge in order to solve problems. A geometric perspective can offer an entirely new way to solve existing systemic problems.

Many processes have evolved from subjective craft into rigorous science through the application of mathematics. We note there are parallels between the current state of fashion patternmaking and the history of early mathematics before it became "rigorous". At present there are multiple patternmaking systems that all have their own rules, most lacking consistency with some being simply a list of instructions. They are in fact more like a set of guides where the patternmaker's intervention is continually required. This resembles the early state of mathematics before "rigour" set in. Indeed, Trudeau calls early mathematics a "hodgepodge of geometric recipes, rules of thumb, and empirical formulae" (1987, p. 1) - thereby accurately describing the current state of fashion patternmaking. We suggest that fashion patternmaking is at present a subjective craft, that with the application of mathematical rigour could lead to rapid technological advancement.

Before early mathematics became "rigorous", it was more akin to the craft of surveying, relying on the subjective measurements of highly-skilled measurers. For example, the mathematical term "hypotenuse" in Greek originally meant "stretched against" (Mlodinow 2002, p. 7), referring to an ancient Egyptian profession called "*harpedonopta*" or "rope stretcher". Ancient Egyptian surveyors needed to accurately measure right angles in order to create buildings. They did not have modern tools for measuring angles and did not understand the mathematics behind triangles. They did however know a trick whereby they could stretch ropes between three people in a 3, 4, 5 ratio in order to create a triangle with a right angle (see figure 36, below). This ingenious rope-stretching technique was in fact a skilled art form.

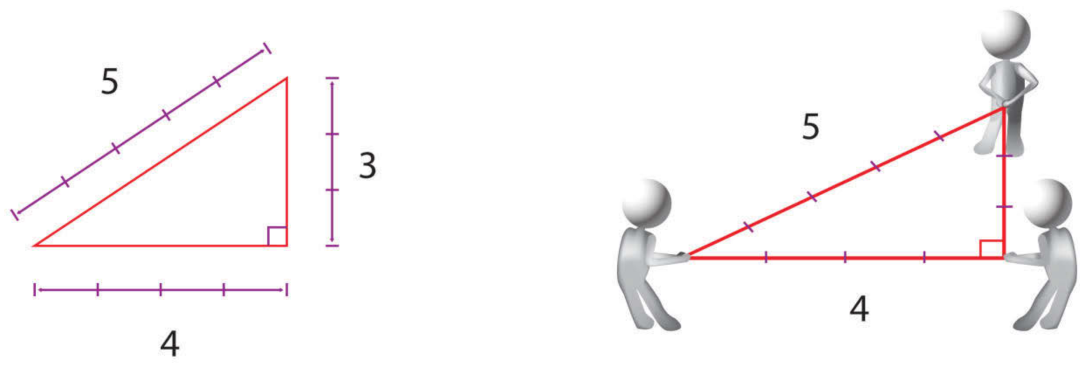


Figure 36: The "*harpedonopta*" or rope stretcher is an ancient Egyptian profession where ropes are stretched in a 3, 4, 5 ratio to create a right angle.

There is nowadays no need for a team of skilled people to stretch ropes in order to measure a right angle. Instead, modern mathematicians understand the underlying mathematics of trigonometry, allowing them to deduce different-sized angles using logic. The term "hypotenuse" now simply describes the longest side of a right-angle triangle. Something that was once a labour-intensive, skill-based, highly subjective craft has now become reliable and commonplace, due to mathematics.

A new synthesis of geometry-based patternmaking systems

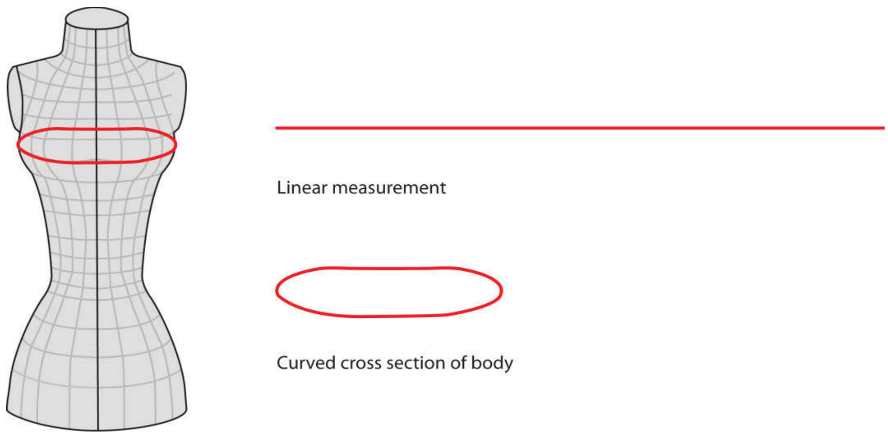
Our thesis has systematically promoted the view that to create a new system of patternmaking based on a combination of Euclidean and Non-Euclidean geometry may have the potential to go far beyond the limitations of existing systems. Any new system will surely be based on a fundamental understanding of the geometric properties of patternmaking. Such understanding will bridge the gap between systems and promote communication between patternmakers, at the same time offering a new and empowering set of tools and techniques. To understand and manipulate patterns in greater detail is to enable new creative possibilities through the construction of more complex forms. Patternmakers with traditional skills and experience must be empowered to use these techniques to enhance their existing practise. A geometric framework to explain patternmaking should also offer an alternative way to teach and communicate patternmaking, and should offer a theoretical framework for the implementation of Non-Euclidean geometry into patternmaking for those who program three-dimensional scanning algorithms.

A more rigorous patternmaking system introduces new possibilities. For example, movement has always proved one of the most elusive elements in patternmaking. A single movement or change in posture can completely change the fit. Existing systems lack the precision to accurately map the garment's shape as the body changes shape over time. A new geometry-based system makes it possible to record the body shape with greater precision and thereby map a pattern as it changes over time. Better understanding of how movements change patterns, allows us to design garments that can better anticipate those movements.

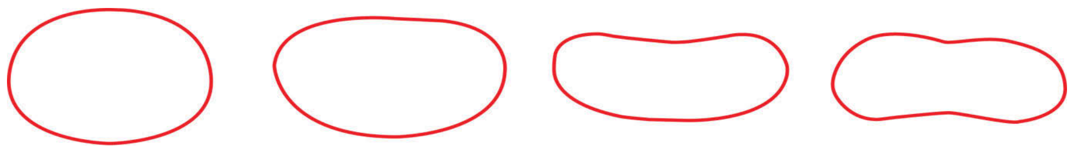
Non-Euclidean explanations for problems with linear measurements

Non-Euclidean geometry can explain the problems encountered by patternmakers when taking linear measurements off the (curved) body and turning them into flat patterns. Many fashion technologists including Whife (1965) are critical of the limitations of linear measurements. Traditional techniques use tape measures to transpose linear measurements off a curved surface into a flat pattern. From a Non-Euclidean perspective, curved measurements cannot simply be transposed onto a flat surface. To measure a curved three-dimensional surface requires a completely different approach. Measurement taken on a curved surface is known as a "geodesic"- the shortest path between two points on that curved surface. It is absolutely not the same as a straight line on a flat Euclidean surface.

To understand the geometric properties of a geodesic it is essential to find the curvature of the surface. The curvature can be either hyperbolic or spherical, and these have completely different rules and geometric properties (Refer to figures 13 and 14). Without knowing the curvature of the surface that a geodesic is on, the measurement lacks critical information. Linear tape measures are incapable of recording the curvature (see figure 37, below), explaining the need for the patternmaker to constantly intervene when measurements become inaccurate.



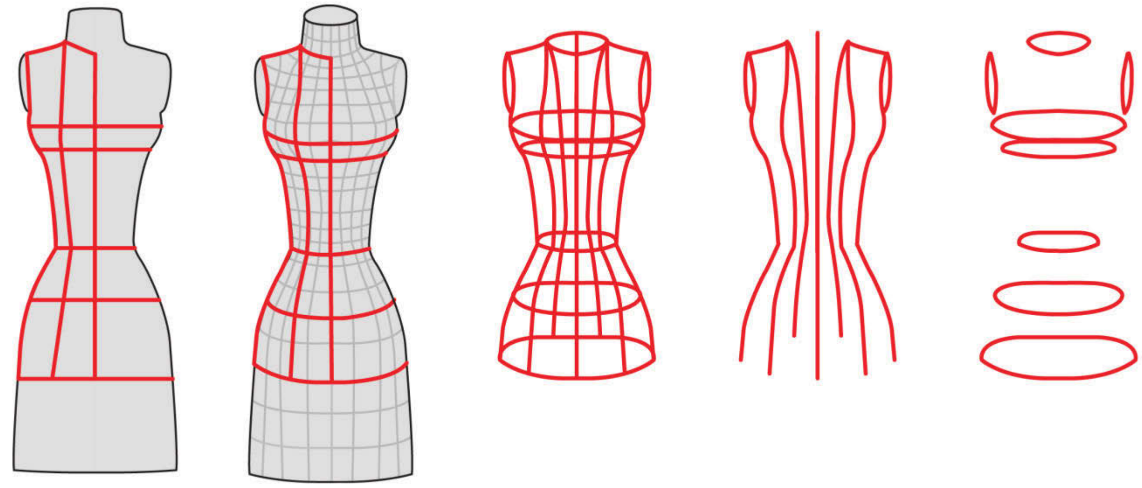
Linear measurements are taken of cross-sections of the body.



These cross-sections all have the same linear measurement, but are different-shaped curves in terms of the body.

Figure 37: Linear measurements are limited in their ability to record the shape of the body.

From a geometric perspective, the linear measurements a patternmaking system takes from the body are all geodesics (see figure 38, below). That is, they are all curved surfaces, yet are measured using a Euclidean paradigm for flat surfaces. This explains why traditional techniques need subjective observations and trial-and-error fittings, whereby the patternmaker must compensate for three-dimensional data that cannot be recorded by the tape measure.



In traditional patternmaking body measurements are recorded as linear measurements.

From a geometric perspective these body measurements in three dimensions are actually geodesics.

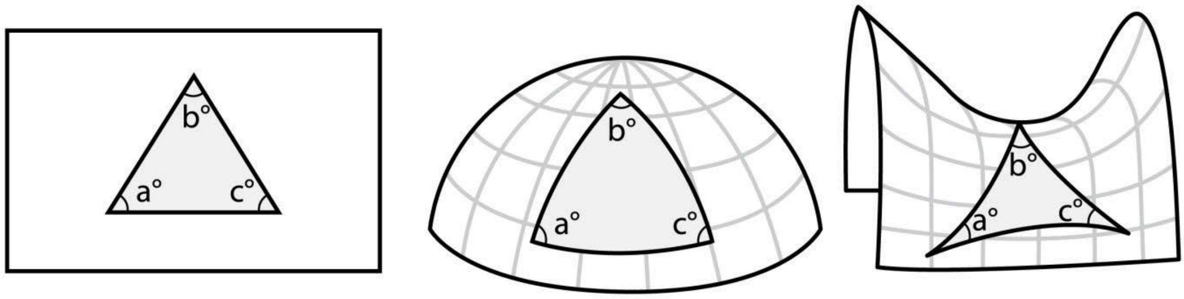
Traditional body measurements are geodesics, and linear measurements cannot record all this information.

In Non-Euclidean geometry each curve has its own geometric identity. This provides more information than a mere linear measurement.

Figure 38: Traditional patternmaking techniques records linear measurements. However, from a geometric perspective measurements are geodesics.

We persistently see that one of the great problems encountered in patternmaking is that traditional techniques are built on a Euclidean paradigm, with all its attendant mathematical logics and assumptions. For instance, assumptions about the length of a measurement, the number of angles in a revolution and the ability to calculate the length of a triangle, are all based on Euclidean principles. Non-Euclidean geometry introduces a much more complex paradigm whereby the curvature of a surface governs its geometric properties. Hereby, spherical and hyperbolic geometry have completely divergent rules (see figures 39 and 40, below). Take the example of a triangle: drawn on a Euclidean surface it has angles that sum to 180˚ (see figure 39). On a hyperbolic surface the triangle has angles that sum to less than 180˚ (figure 39), while on a spherical surface its angles sum to greater than 180˚ (figure 39). Consider a further example. In patternmaking, measurements may be drawn at 90˚ from the centre front line to make them horizontal. However, in Non-Euclidean geometry they can be more or less than 360˚, and 90˚ may not be a horizontal line (see figure 41, below). This demonstrates how a Euclidean paradigm, entrenched into traditional patternmaking techniques, has limited accuracy.

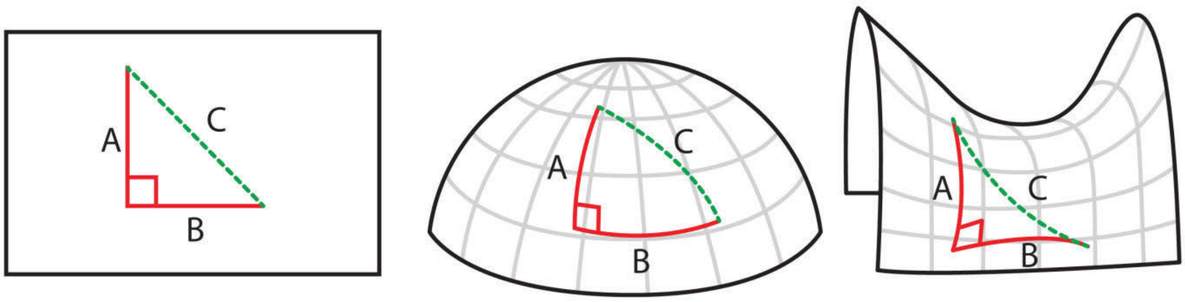
Euclidean | Spherical | Hyperbolic



Euclidean surface: | Spherical surface: | Hyperbolic surface:

$a° + b° + c° = 180°$ | $a° + b° + c° > 180°$ | $a° + b° + c° < 180°$

Figure 39: Comparison of the geometric properties of Euclidean, spherical and hyperbolic geometry.



Pythagorean Theorem

Euclidean: $a^2 + b^2 = c^2$

Spherical: $\cos a \times \cos b = \cos c$

Hyperbolic: $\cosh a \times \cosh b = \cosh c$

Figure 40: Comparison of the geometric properties of Euclidean, spherical and hyperbolic geometry.

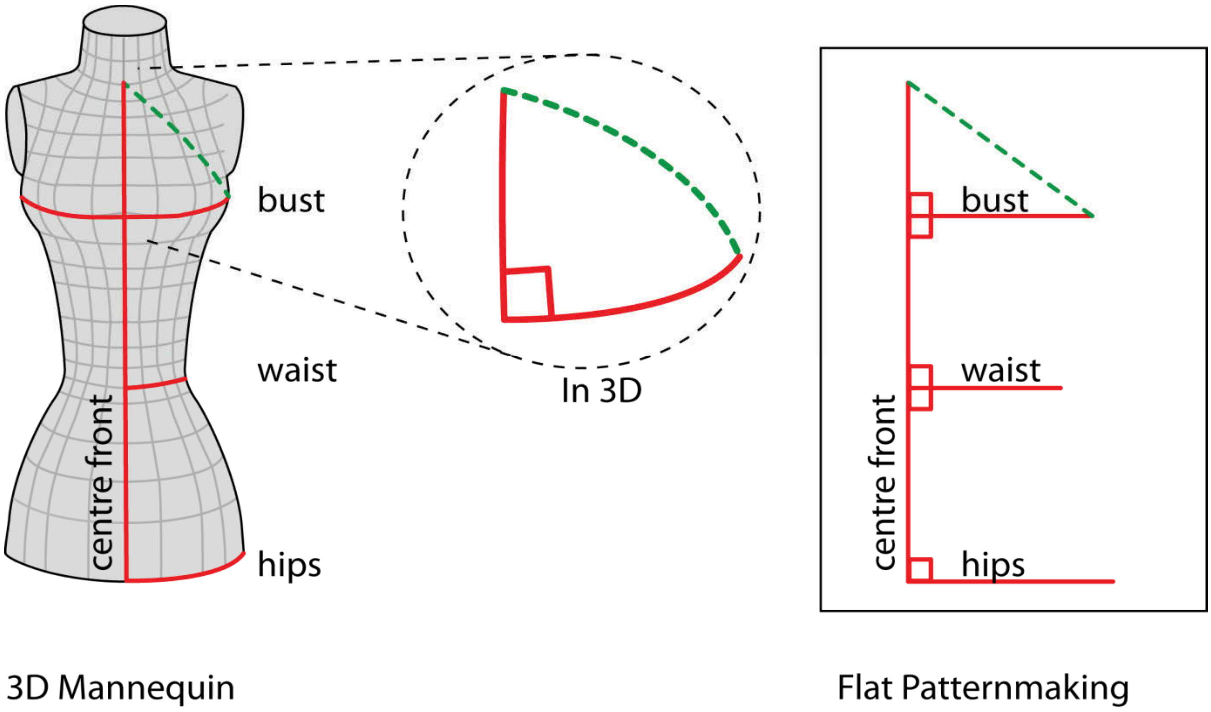


Figure 41: Translating curved measurements onto flat patterns does not consider that Euclidean and Non-Euclidean surfaces have different geometric properties.

Pythagoras' theorem is an equation that allows the hypotenuse of a right-angle triangle to be calculated if we have the measurements of the two sides. Patternmakers often assume when drafting patterns that if they have two lines at a right angle that they can draw a third line to form a triangle (see figure 40). However Pythagora's theorem does not work on a curved surface. Further, spherical and hyperbolic geometry have their own versions of Pythagoras theorem, that work on surfaces with different curvatures (see figure 40). A patternmaking technique that translates two linear measurements at right angles from a Non-Euclidean surface to a Euclidean surface is limited in its accuracy (see figure 41). In sum, Euclidean assumptions that patternmakers make about measuring linear distances and drafting triangles are inaccurate on Non-Euclidean surfaces.

Non-Euclidean geometry allows a more complex view of patternmaking where each part of the body has different geometric properties, namely spherical, hyperbolic or Euclidean. Figure 42 (below) demonstrates how it is possible to identify the different body shapes by their geometry. In terms of the female body, spherical parts include the bust, shoulders, buttocks, shoulder blades and stomach. Hyperbolic shapes include the crotch, underarms, neck and under the bust. Cylindrical body shapes such as arms and legs in turn have properties of Euclidean geometry. Some body parts also change in shape depending on the pose of the body, for example the shoulders.

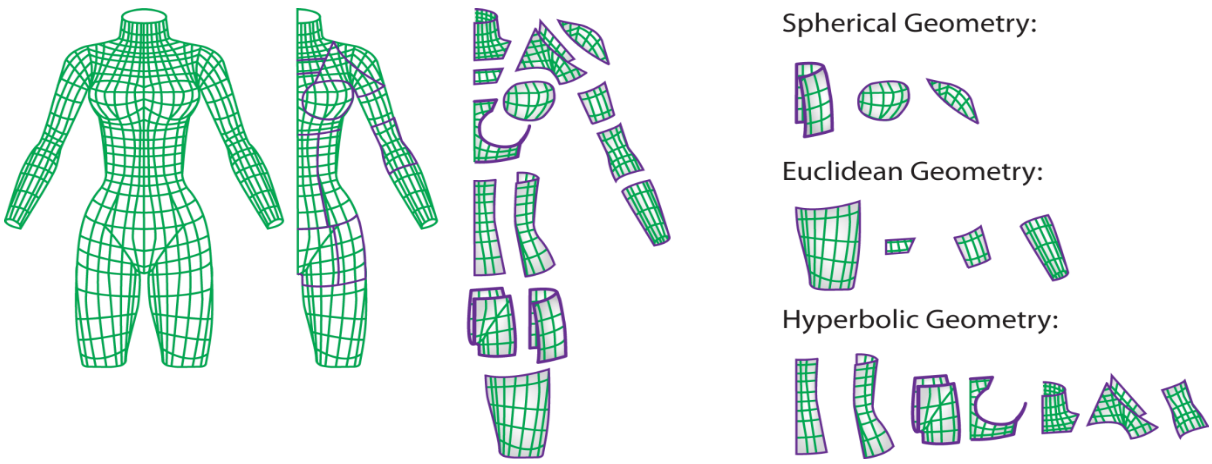
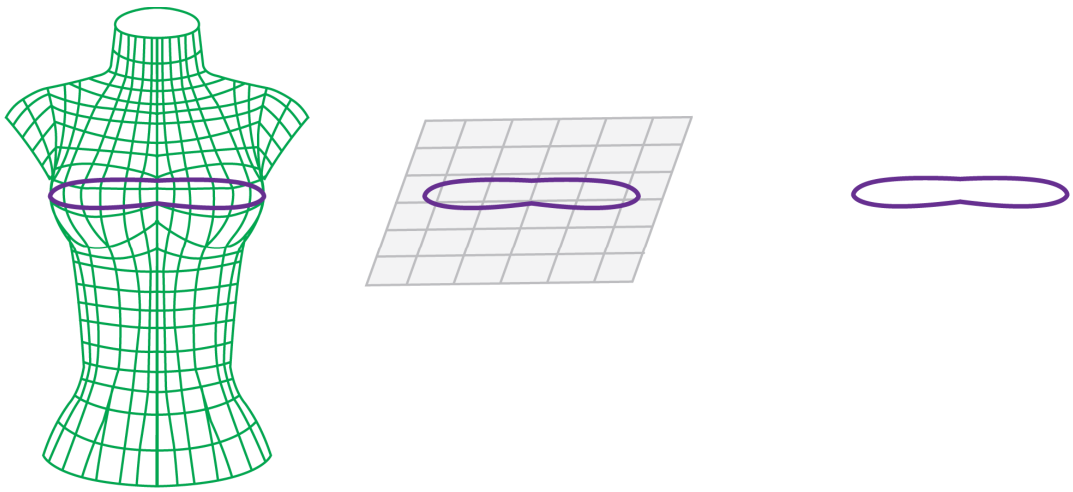


Figure 42: The human body is a complex three-dimensional form wherein each part of the body has its own type of geometry with its own properties. In this diagram a body has been deconstructed into pieces that display Spherical, Euclidean or Hyperbolic shapes.

Another problem in relation to linear measurements is that they have limited ability to record the three-dimensional shape of the body. Even if we could accurately make a curved linear measurement around the body, it still only allows a flat two-dimensional cross-section (see figure 43, below). In computer science these cross-sections are called "splines"- whereby a spline still needs to be combined with other splines in order to construct a three-dimensional surface around the body (see figure 44). Linear measurements are not very accurate in recording the shapes of these splines or where they overlap. Non-Euclidean geometry on the other hand requires the patternmaker to map the curvature of the surface as well as its dimensions.

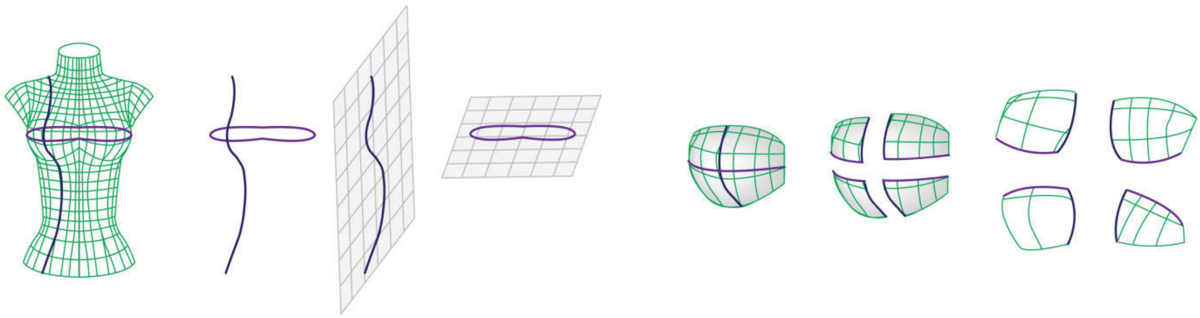


A linear measurement taken on the body.

A linear measurement is actually a flat cross-section of the body.

The curved cross section of the body called a "spline".

Figure 43: A single curved cross-section does not contain enough information to create a flat pattern.



Multiple curved cross-sections are required to capture the body's three- dimensional shape.

Multiple splines are needed to create flat patterns.

Figure 44: A patternmaker requires multiple curved cross-sections in order to create a flat pattern from measurements.

Non-Euclidean geometry can readily describe why patternmaking works well with "ideal" body types and is less accurate on more curvaceous figures. When creating clothes around slender so-called ideal types it is easy to create cylinder-shaped patterns (see figure 45, below). Cylindrical shapes, as flat surfaces that are bent into a cylinder, have Euclidean geometry. People who have fuller, more curvaceous bodies will require the properties of spherical geometry (see figure 45). Patternmaking is more challenging around the curved parts of the body, for example shoulders, neck, bust, stomach and bottom. Traditional patternmaking works well with forms that are more Euclidean in shape, but are less accurate when working with spherical or hyperbolic geometry. Non-Euclidean geometry thereby explains why those traditional techniques are less effective when working with curved surfaces.

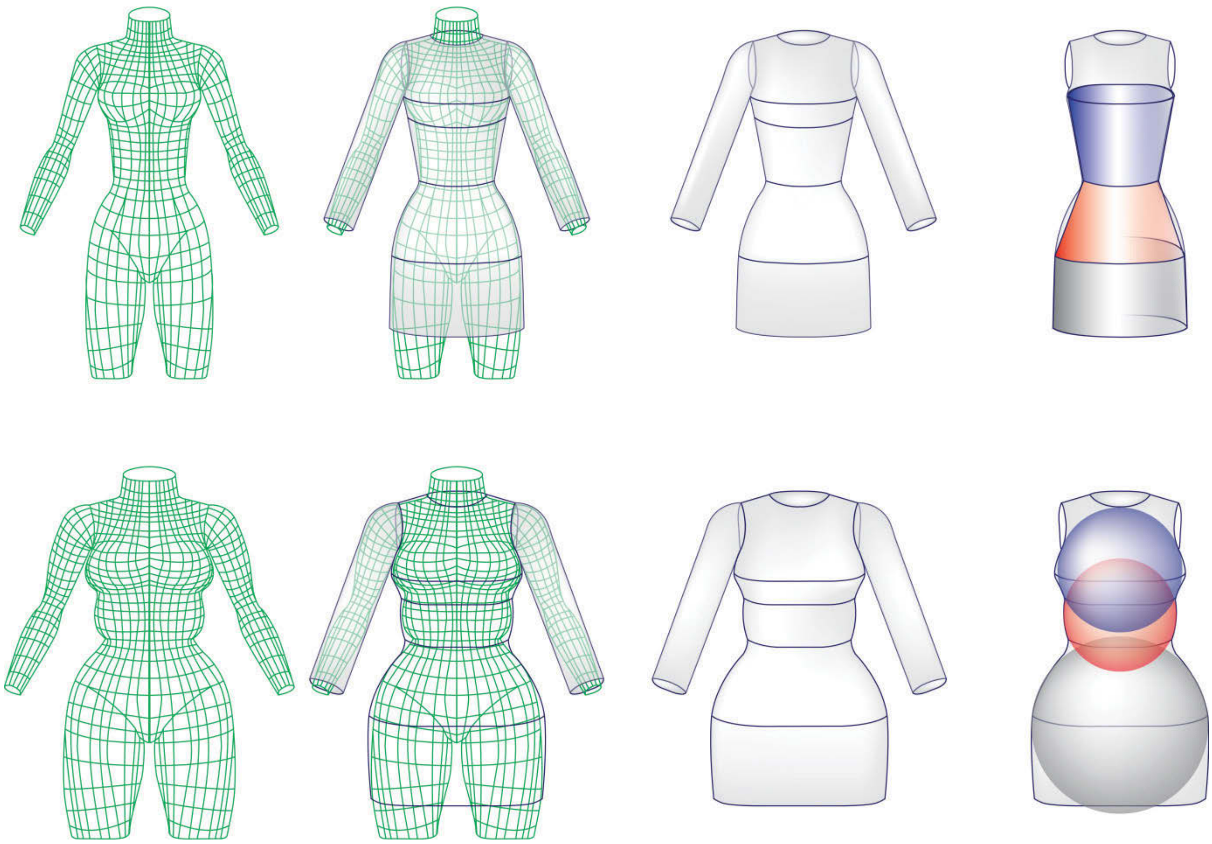


Figure 45: It is easier to make patterns for body-forms that have less curvature. These patterns resemble flat Euclidean geometry. Curvaceous body forms tend to be more challenging and resemble spherical geometry. A Non-Euclidean perspective explains why making spherical patterns for bodies is less accurate.

Patternmakers need keen judgement and observation to record three-dimensional details that cannot be recorded by the tape measure. Yet recording such 3D information through judgement and observation alone is vague, subjective and incredibly hard to communicate. Non-Euclidean geometry gives patternmakers a methodology to record these 3D details. Under a Non-Euclidean system we still place great value in judgment and observation, but Non-Euclidean geometry will inevitably make traditional skills more accurate in that it simplifies three-dimensional shapes and makes patternmaking easier. A more precise system lets the patternmaker focus on important issues such as aesthetics and design. Further, instead of describing the body with vague and subjective experiences, Non-Euclidean geometry creates a new language that can be shared and communicated.

Non-Euclidean geometry and systemic problems with 3D algorithms

In recent years the rise of computers and three-dimensional scanning technology has offered new possibilities for recording the shape of the body, though it should be said that the new technology did not guarantee perfectly-fitting garments. There are many technical problems in reverse engineering 3D scans into 2D patterns that can be used to make real-world garments (Watkins 2011, p. 245). Many of the generated patterns are inaccurate or unusable in manufacture. Other patterns are so complicated that traditional patternmakers find them difficult to manipulate (see figure 46, below), highlighting the challenge these algorithms face in not being designed by patternmakers and ignoring many principles of traditional techniques.

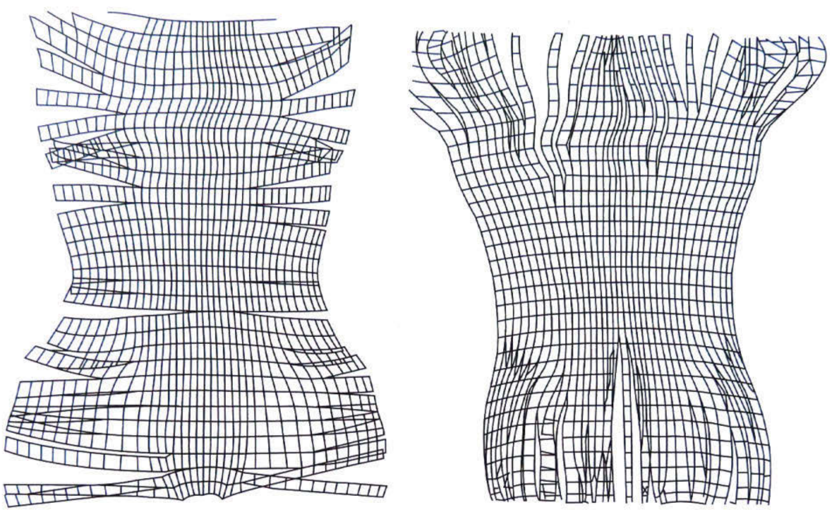
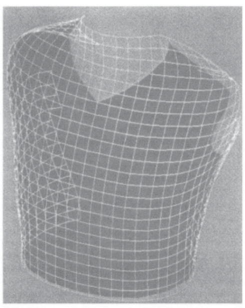


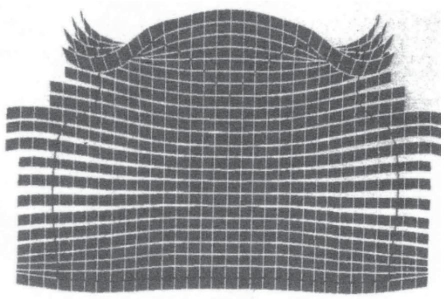
Figure 46: An example of a flat pattern generated from a three-dimensional scan, by Kurokawa and Nishimura (Yu *et al.* 2006, p. 107). This pattern is so complicated, it is impractical for traditional patternmaking.

A key problem encountered by patternmakers is that their concepts are not compatible with three-dimensional scanning algorithms. Computer scientists are not able to interpret traditional systems that rely on human intuition and experience, tending instead to create patterns that rely on mathematical principles for flattening 3D shapes into flat patterns. Flattening 3D curved surfaces often creates so many complex seam lines that they are completely impractical (see figure 47, below).

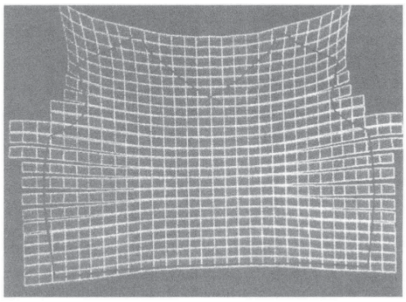
Traditional patternmakers avoid this problem by using their judgement to simplify complex cured shapes into a form that can be easily flattened into a pattern. Meanwhile, traditional patternmaking has its own weaknesses. Traditional techniques that draft patterns from body measurements create mere approximations, whereby the quality of the fit is often based on individual skill and an iterative fitting process. Any computer program that automates traditional drafting creates an approximation. Computer algorithms simply do not have the intelligence of a human patternmaker.



A 3D scan of a body form with mesh superimposed on the garment.



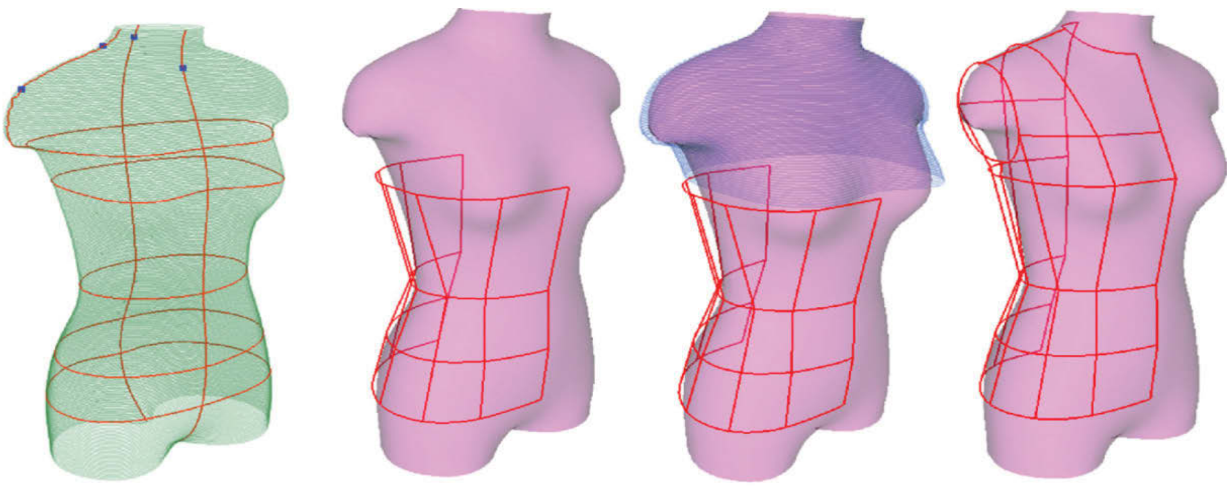
The 3D mesh is flattened into a garment pattern. Some parts of the patterns are overlapping.



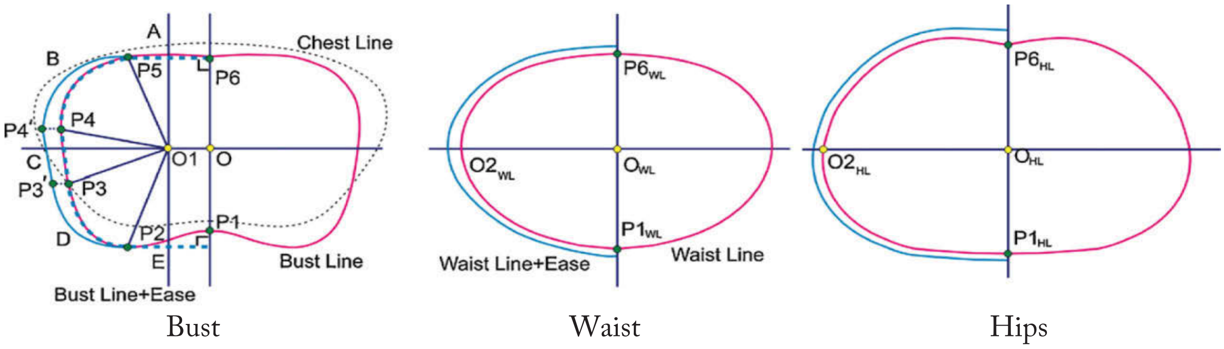
Overlaps of the pattern are eliminated by spreading out the pattern.

Figure 47: Flat patterns created from 3D scans tend to be overly complex and impractical for turning into commercial patterns (Kwong 2004, p. 222 - 223).

While a grasp of the underlying technical elements of patternmaking and mathematics seems to be an effective way of improving both traditional and hi-tech approaches, there are unfortunately few individuals who can navigate the path between them. The team of Huang, Mok, Kwok and Au have made a start in introducing concepts from traditional patternmaking into computer algorithms (Huang *et al.* 2012, pp. 680 - 683). They are in turn critical of how so many algorithms tend to completely ignore traditional concepts such as “ease”, and tend to create patterns that are impractical to sew (see figure 48, below). What makes this team stand out is that members have PhDs in physics as well as skills in traditional patternmaking. Their skill with both high-level mathematics and traditional techniques is very rare. They have developed computer algorithms which generate accurate block patterns from 3D scans. This approach is different to other such scans in that it engineers a fitted piece of clothing on top of the scan instead of simply flattening a scan of the body.



(Huang *et al.* 2012, p. 685)



(Huang *et al.* 2012, p. 684)

Figure 48: The clothing patterns created by Huang *et al.* identify key points on the body and built a garment around the three-dimensional shape of the body which includes ease (2012, pp. 684 - 685).

Generating accurate block patterns from 3D scans is a great breakthrough for patternmaking, yet there are still many technical challenges that limit traditional techniques. In the case of Huang *et al.* the curved darts and contoured edges of the garment help shape the garment so that it fits the body. These contours also create seam lines which become the garment's design. Designers use block patterns in order to design by moving the style lines around the garment while maintaining the same fit. However, these patterns are very detailed, and their contours and curved darts are extremely difficult to manipulate using traditional contour techniques (see figure 49, below). As soon as the patternmaker needs to move one of the seam lines or darts, the pattern loses the accuracy in the fit.

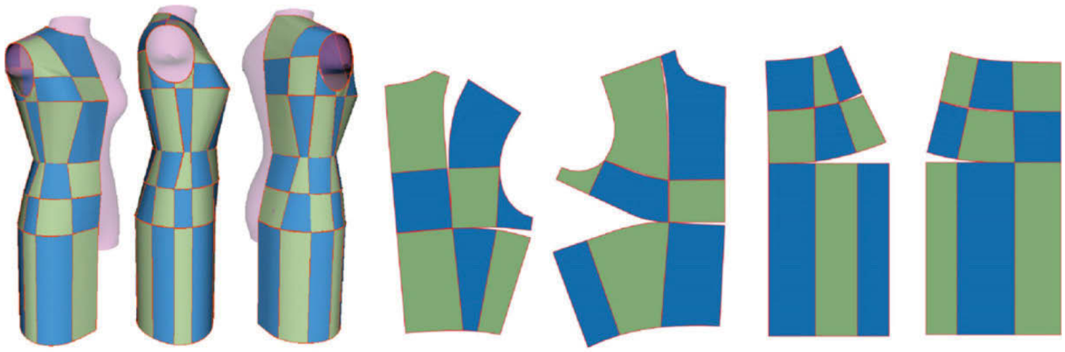


Figure 49: These patterns are extremely detailed and use contoured patterns. Unfortunately such detailed patterns are difficult to use with traditional techniques without losing accuracy (Huang *et al.* 2012, p. 683).

Three-dimensional scanning technology maps each point on the body as coordinates in three-dimensional space. This data is stored as a cloud of points that can be interpreted into three-dimensional shapes (see figure 50, below). The 3D forms are stored in the computer as a curved Non-Euclidean surface (see figure 51). Programmers who write 3D algorithms seek to interpret traditional techniques into Non-Euclidean geometry, yet so far attempts to bridge the gap have had only limited success. The complex mathematics required to measure curved surfaces alienates traditional patternmakers while the guidelines, rules of thumb and reliance on approximations deter computer scientists from integrating traditional techniques into computer algorithms. These approaches may seem like polar opposites, yet bridging the gap is the key to creating a more powerful system than either alone can achieve.

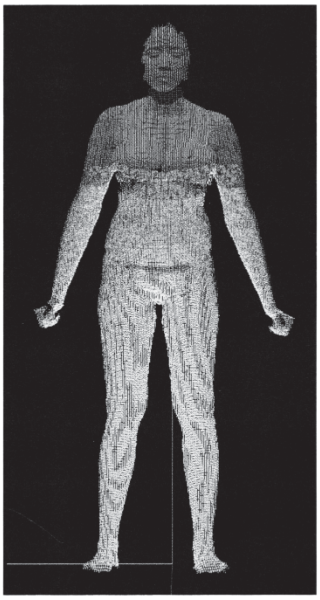


Figure 50: A three-dimensional system records the body as a cloud of points (Fairhurst 2008, p. 99).

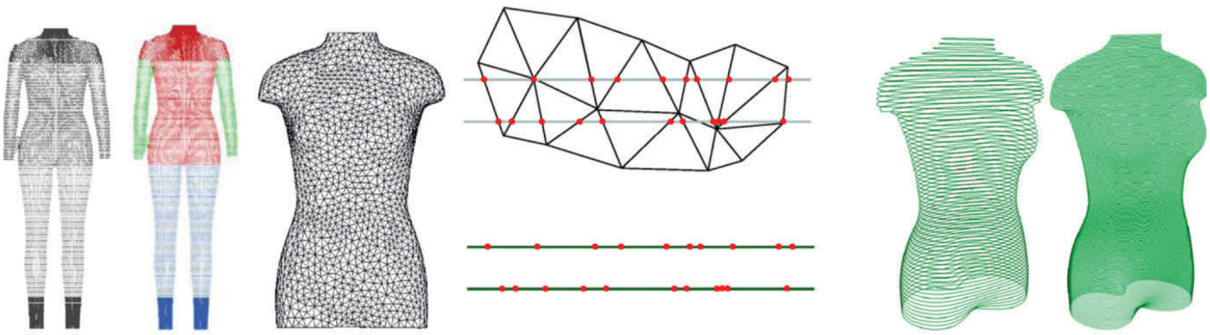
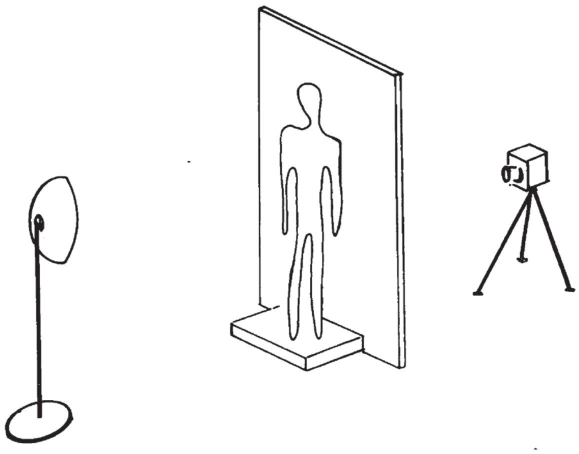


Figure 51: 3D scanners record the shape of the body as a cloud of points. The data is then interpreted into a 3D wireframe that can be manipulated by computer software (Huang *et al.* 2012, p. 683).

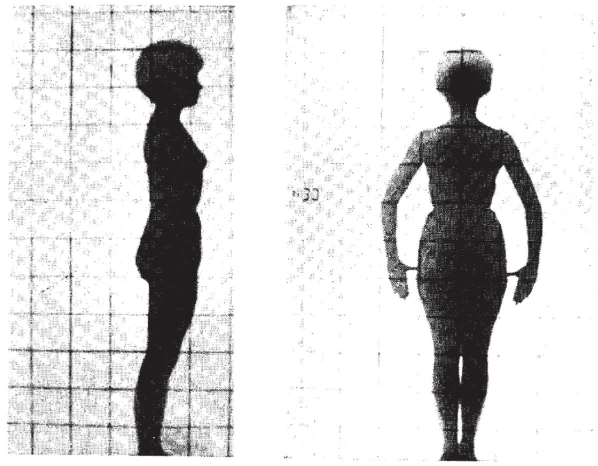
Learning from fashion technologists

Many fashion technologists have attempted to develop more accurate techniques that require less trial-and-error fitting (Kwong 2004, p. 201), using mathematical algorithms, CAD systems and 3D scanners. We have seen how difficult it is to take 3D shapes and flatten them into patterns for the benefit of fashion patternmakers (see figure 44), since designs are perennially inaccurate and impractical. However, some technologists have developed ideas we can learn from. Efrat (1982), Chen (1998), Kwong (2004) and Yu (2004) have developed detailed literature reviews of some of the best techniques. We now offer examples of those that have provided inspiration.

In the 1960s, at a time before three-dimensional scanners and powerful computers, fashion technologists such as Douty and Zeigler developed a principle called "graphic somatometry" (Kwong 2004, p. 201). This is the process of photographing the silhouette of the body and analysing the curved cross-sections (see figure 52, below). These cross-sections are initially used to identify fitting problems caused by different shapes and postures. Visual somatometry was further refined by Winakor *et al.* (Kwong 2004, pp. 202 - 204) who developed a set of equations for a fitted bodice pattern (see figure 53). Brackelsberg *et al.* addressed the complex shape of the waist by developing a pattern for a bodice joined to a skirt (Kwong 2004, p. 202). Heisey also developed a method which focused on finding a mathematical formula for the pattern of the bodice (Kwong 2004, pp. 202 - 213). One key challenge identified was to work out the size of the dart required to shape the garment around the bust (see figure 54). Kwong states that "though success with this methodology has been limited, the approach offers the potential for providing more accurate measurements than the traditional method of body measurement" (Kwong 2004, p. 202).

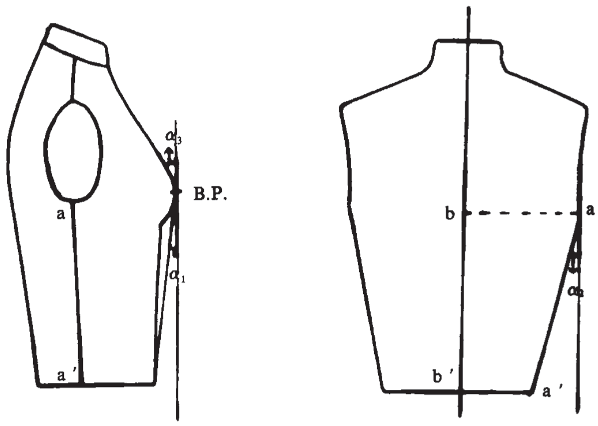


The process of "Visual Somatography" (Douty 1968, p. 24).

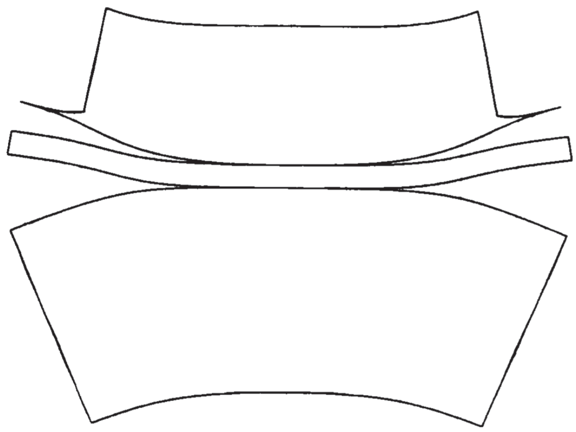


The body is captured as the silhouette of a photographic image (Douty 1968, p. 26).

Figure 52: Douty developed "Visual Somatography", using a photograph of the silhouette of the body to determine accurate measurements.



Side and front view taken from a somatograph form. (Winakor *et al* 1990, p. 51)



A computer pattern of the bodice created from a somatograph form. (Winakor *et al* 1990, p. 50)

Figure 53: Winakor *et al.* (1990) developed techniques that allowed visual somatography images to generate flat patterns.

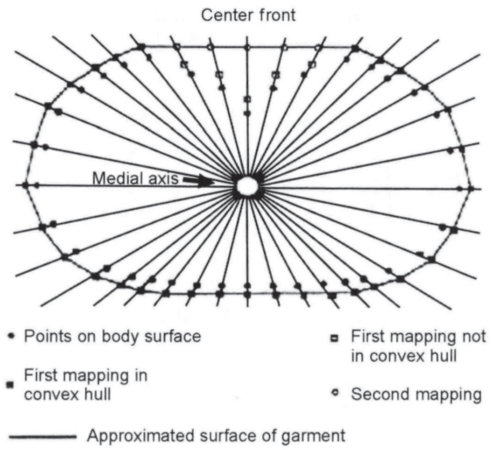


Figure 54: Heisey developed techniques for mapping the bust level of the garment from 3D data (Kwong 2004, p. 211).

Fashion technologists of the 1980s and 1990s had access to more sophisticated computer technology, and could now record the shape of the body as a series of coordinates in a computer. Efrat (1982) developed the "conical principle" which divided the body into 26 crucial shaping points, and measured the body as a series of triangles (see figure 55, below). This approach takes these linear measurements and uses a computer program to calculate the cone angle of the dart to draft a flat pattern. This technique was not particularly effective since it was difficult to take accurate linear measurements, and a single inaccuracy in any of them would distort the entire pattern. Yet it has useful ideas, such as using conics (the study of cones) to work out flat patterns for a three-dimensional form. Efrat concluded that "the problems associated with achieving good-fitting garments are caused by the unsatisfactory nature of the measurements obtained when measuring the human body by traditional methods, and that the traditional methods of body shape determination are far from accurate" (Kwong 2004, pp. 208 - 209). This in turn inspired the research to find a solution based on conics and Non-Euclidean geometry.

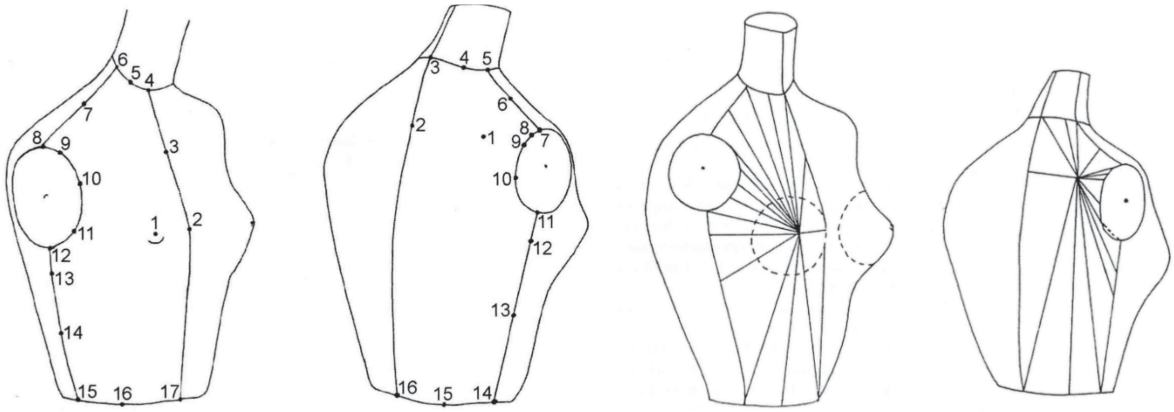


Figure 55: Efrat developed a conical technique that used 26 crucial points to create a flat pattern (Efrat 1982, pp. 76, 103 & 106).

To get a 3D shape into a flat pattern is a challenge many technologists are still trying to resolve. Kwong in his literature review states "Therefore, a scientific investigation into the problems of achieving a two-dimensional block pattern which can accurately reflect the three-dimensional nature of the human body, could well be of extreme significance to the clothing and tailoring trades" (Kwong 2004, p. 208). The approach taken by Hinds *et al.* (1991) is typical of flattening 3D shapes into flat patterns (see figure 56, below). The algorithm used here flattens patterns in a way that is simply not practical for the fashion industry, in that it is so detailed that it is impractical (see figure 56). The flat pattern contains an excessive number of darts, of which some have complex contours, and some overlap to create gussets. The pattern is inefficient, expensive to manufacture and with its multiple seam lines ruins the aesthetic of the garment.

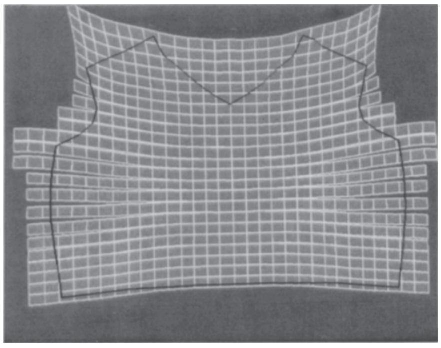


Figure 56: A 3D scan creates a pattern with so many darts that it is impractical to make a garment from the pattern (Hinds *et al.* 1991, p. 590).

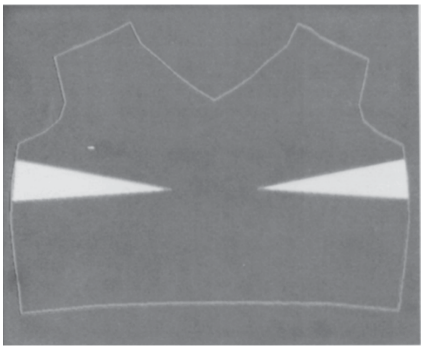


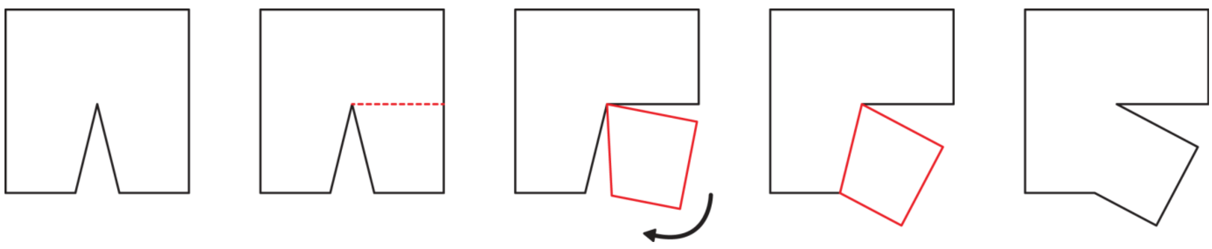
Figure 57: The algorithm creates a pattern that is over-simplified and does not make full use of the data acquired from the 3D scan (Hinds *et al.* 1991, p. 590).

Figure 58: The outcome is a garment not particularly accurate or aesthetically appealing (Hinds *et al.* 1991, p. 590).

Hind *et al.* acknowledge this problem and attempt to simplify the flat pattern. "To provide a pattern that the clothing trade would recognize, it is possible to group the small darts together to form a single large dart at specific locations. Also, to deal with gusset or overlap areas, strands can be rotated to eliminate overlaps" (Hinds *et al.* 1991, pp. 589 – 590). This refers to the practise of "dart manipulation" used to manipulate block patterns by fashion patternmakers (see figure 57). Here, the creators of the algorithm have implemented their own version of dart manipulation. This is not based on a traditional patternmaking technique but a rough approximation generated by the algorithm. From a patternmaker's perspective the algorithm discards most of the detail of the original scan in favour of a very crude approximation. This simplified version of the pattern is inaccurate and aesthetically unappealing (see figure 58). In short, the scanning process fails to capture and translate the original shape of the body into a garment. Although unsuccessful, the Hind *et al.* paper offers great insight into many of the problems between 3D algorithms and traditional patternmaking practises.

The paper by Hind *et al.* (1991) forced researchers to question many of the fundamental ideas of fashion patternmaking. Hind *et al.* demonstrates that 3D scans are extremely detailed and complex, with the resulting patterns generating multiple darts with complex contours. Working with such complex shapes requires a level of precision beyond the reach of traditional fashion patternmaking.

Patternmaking is more than simply re-creating a three-dimensional form. There is skill in finding the optimal form that accommodates the shape of the body and can be efficiently manufactured. Traditional patternmakers tend to avoid overly complex patterns, instead creating simple ones that rely on the stretch properties of the fabric to accommodate the body's curves. Clearly, there is a need for a new way that would allow traditional patternmakers to accurately manipulate the complex curves created by 3D scanners. Modern research explores "dart manipulation" in some detail. This technique moves the location of the dart while maintaining the shape of the original garment (see figure 59, below). It works well with simple straight-edged darts, but dart manipulation becomes complex when working with complex curved seam lines. In the examples of Hind *et al.* there are so many darts that traditional fashion patternmaking has difficulty manipulating them. Manipulation of complex darts is thereby a problem for both 3D algorithms and traditional patternmaking.



1: A pattern with a dart. 2: Cut a new dart line. 3: Pivot dart pattern. 4: Close dart. 5: A new dart is created.

Figure 59: The process of dart manipulation. The original pattern and the new pattern have different dart locations, but make up the same three-dimensional shapes.

Hyperbolic crochet and Non-Euclidean geometry

Daina Taimina is a mathematician who is able to visualise equations from hyperbolic geometry by making them out of crochet. In her book *Crocheting Adventures with Hyperbolic planes* (2009) Taimina models Non-Euclidean surfaces by making models out of paper and crochet (see figure 60, below). In figure 61 we see physical models of mathematical functions and geometric surfaces, elements recognisable to patternmakers. She uses "darts" to create elliptical surfaces and "gussets" to create hyperbolic surfaces. These models, being visual and tactile, are especially accessible to designers. Henderson and Taimina have also published technical books, including *Experiencing Euclidean and Non-Euclidean Geometry with History* (2005). This book describes techniques for measuring distances over curved hyperbolic or elliptical surfaces. Some of the techniques require the reader to not only manipulate mathematical functions but understand integral calculus, in order to calculate distances on curved surfaces (see figure 62).

I learned about the hyperbolic plane from this paper model.

My first model of the hyperbolic plane made in 1997.

Figure 60: Taimina created models of hyperbolic mathematics out of paper and crochet (Taimina 2009, pp. 5 & 20).

Figure 61: Taimina made physical models of mathematical concepts. Her models of positive and negative curvature resembled the darts and gussets used by fashion patternmakers (Taimina 2009, p. 14).

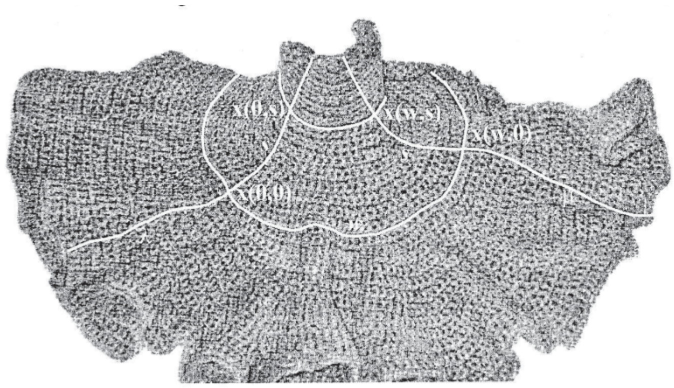


Figure 62: Distances can be calculated on a hyperbolic surface using geodesic co-ordinates. These calculations require the use of calculus (Henderson & Taimina 2005, pp. 67 – 68).

Seeking the right mathematics for patternmakers

Even with knowledge of Non-Euclidean geometry there are still many challenges to finding practical applications for fashion patternmaking. Mathematics tends to use idealized geometric forms which celebrate the beauty of mathematics over practical applications. Most of the geometry allows the accurate measurement of areas and distances on perfect spheres or on orderly hyperbolic shapes. For instance, there is a formula for calculating the area of a triangle on a sphere (see figure 63, below).

Unfortunately such ideal shapes are not so common in patternmaking. In truth, patternmakers encounter much more irregular shapes, making the required mathematics much more complex.

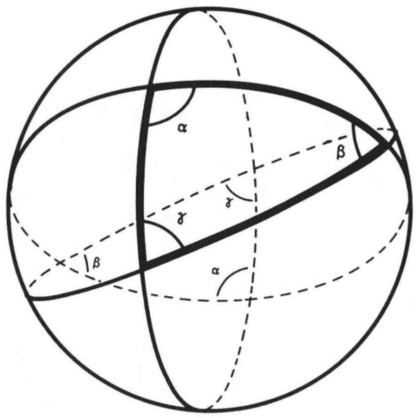


Figure 63: Equations that find the area of a triangle on a sphere (Weeks 2002, p. 140).

The challenge of working with complex three-dimensional shapes forced mathematicians to begin to rely on computer simulations. The use of computer programs in turn began to take control away from the user, due to the high level of expertise and background knowledge needed to operate them. Our research increasingly realised that such complexity would overwhelm most patternmakers. Even if a patternmaker is trained to operate the software, it would not give them any greater control over their patternmaking. There would simply be no greater understanding of how it worked. It became clear to our research that the challenge is to find the right form of mathematics within the grasp of fashion patternmakers, yet within the principles of Non-Euclidean geometry.

It is always a challenge to communicate sophisticated mathematical ideas to patternmakers who may have no prior knowledge of mathematics. Mathematics is built on theorems or proofs that take time and effort to learn. For the average patternmaker, trying to grasp this level of mathematics is like trying to read a foreign language. There is no point developing a technique so complex no patternmaker can understand it. To our research, the problems seemed overwhelming (as his exhaustive survey has shown) , yet the research has persisted in seeking an analysis of what makes the application of mathematics in patternmaking so intractable.

Our research identified scenarios where mathematics has been successfully adopted by different industries. Many of these scenarios do lead to dead ends or to mathematics so complex they is impractical to use. The two industries that survived mathematical rigour are origami and the techniques of sheet metal workers, developed in the 1950s. In these industries traditional craftsmen could still be creative and expressive while using mathematical principles to gain greater accuracy in their techniques. The research explored what actually made the mathematical applications accessible to such traditional practitioners.

Our research drew inspiration from origami as it embodies a traditional art form that rapidly developed in sophistication out of the application of mathematical rigour (see figure 64, below). The first attempts to analyse origami as a set of geometric axioms came from Margherita Piazzolla Beloch in 1936 (Demaine & O'Rourke 2007, pp. 168 - 169). The work of Erik Demaine further codified many traditional practises of origami into rigorous mathematical proofs. His proofs made the art form's fundamentals more accessible from a mathematical point of view. Robert Lang is another pioneer of modern origami who found applications for different mathematical fields, and who developed computer algorithms based on mathematical principles to help in origami design (Demaine & O'Rourke 2007, p. 169).

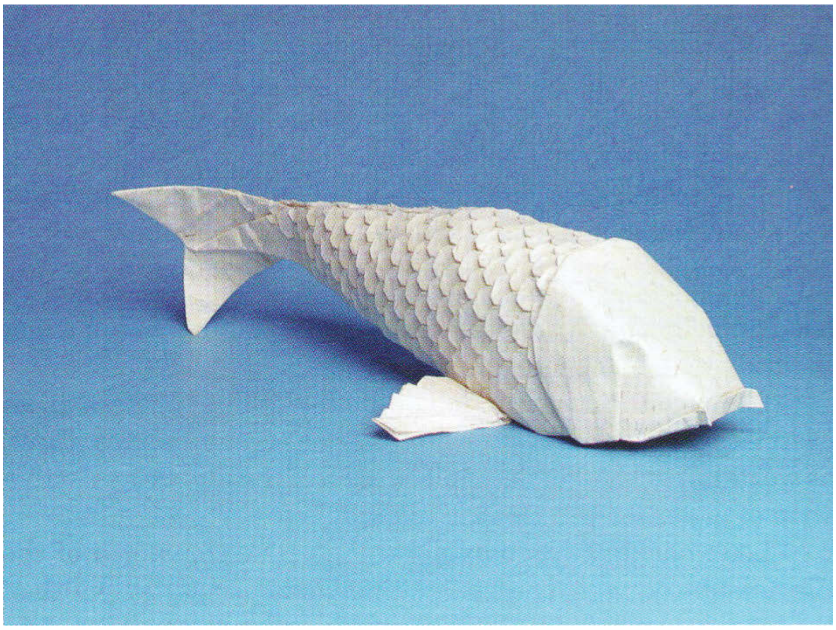


Figure 64: An origami Koi created by Robert Lang. Modern origami is much more detailed and complex than traditional origami designs (Lang 2003, p. 206).

Lang's program *Treemaker* allows skilled experts to build origami so complex it is almost impossible without the aid of a computer (see figure 65, below). Patterns that would take vast amounts of time by trial and error can be calculated in an instant. This is extremely impressive as it allowed the origami artist to increase the complexity of the art form without being overwhelmed by the underlying mathematics. Our research has observed that traditional origami artists are good at manipulating mathematical principles if they are presented visually, can be manipulated by hand, and offer obvious practical applications.

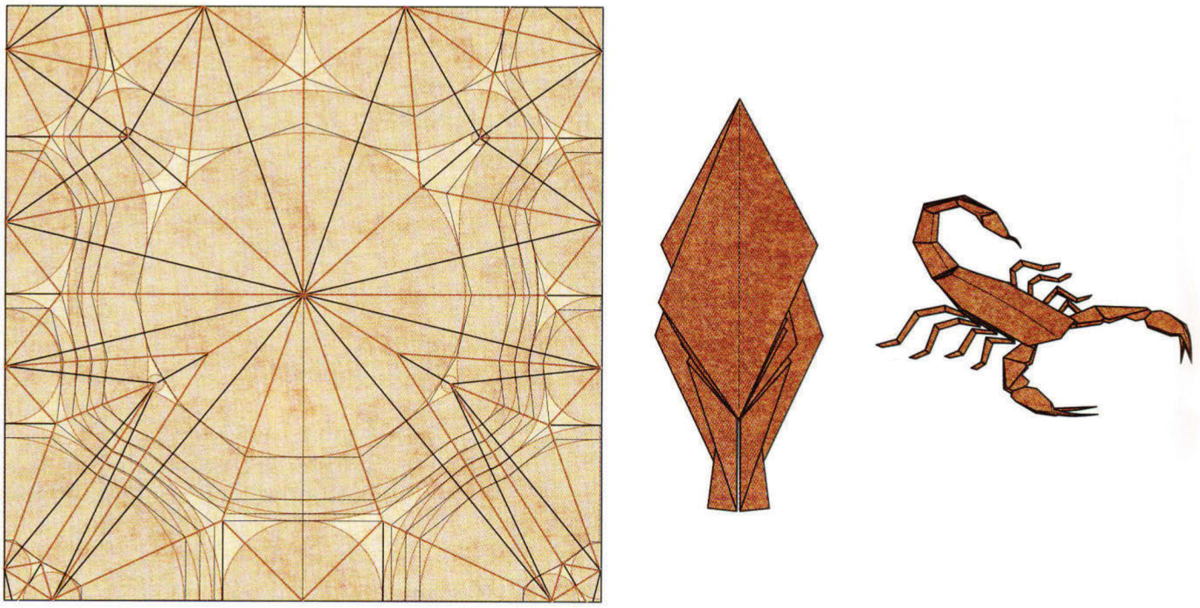


Figure 65: Lang's *Treemaker* program allows origami artists to calculate the folding patterns they need for complex forms, enabling the creation of origami of unprecedented complexity (Lang 2003, p. 406).

While searching for mathematics that linked to patternmaking, our research investigated the techniques of sheet metal working. There are patterns in sheet metal work that strongly resemble those in patternmaking. Sheet metal work has to be particularly accurate since its materials are not as flexible as fabric. Further, it has processes similar to patternmaking in that it develops complex three-dimensional shapes from flat patterns. For example, the shape of a sleeve is similar to a joint in sheet metal work (see figure 66, below). Investigating sheet metal workers' techniques from the 1950s (Cookson 1941) revealed that mathematical rigour is extremely important to sheet metal workers. Their techniques demonstrate practical applications of mathematical ideas that are powerful yet not overly complex, being developed before the invention of the personal computer.

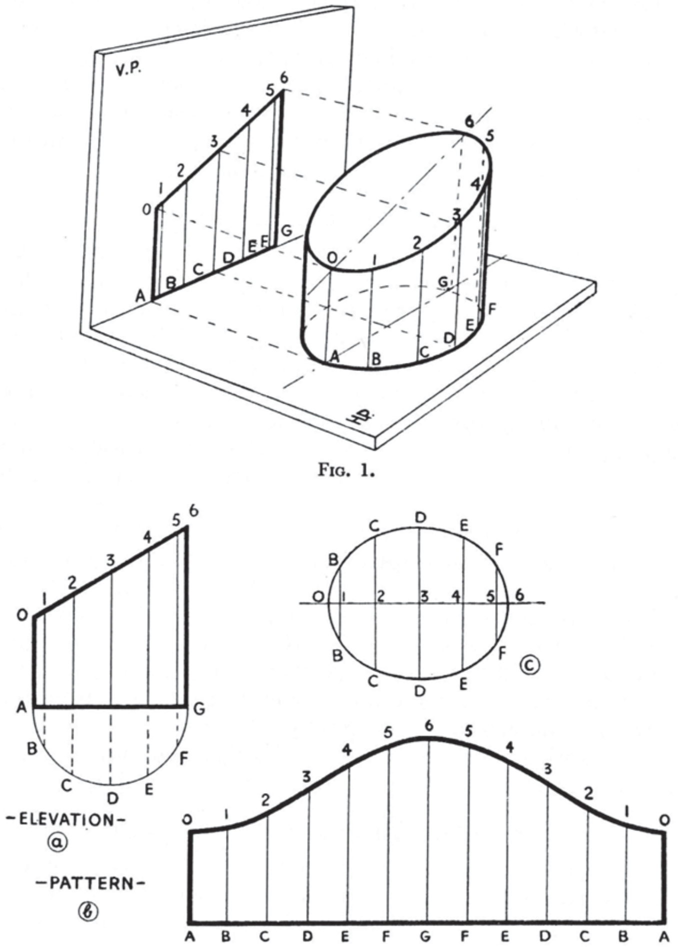


Figure 66: Sheet metal working techniques resemble the patterns used in sleeves by fashion patternmakers (Cookson 1975, p. 10).

Sheet metal workers have already undergone the process of mathematical rigorization. This spirit of rigour is captured by the sheet metal worker Cookson (1941, p. 7) who states:

> "It is not sufficient to have a superficial idea of different methods of pattern cutting and then rely on 'rule-of-thumb' methods when a difficult job has to be made. Draughtsmen are too often blamed for what are termed fantastic designs, simply because the average craftsman cannot mark-out the correct pattern for the work".

While Cookson is referring to sheet metal workers, much of what he says applies to modern fashion patternmaking. The approach of making three-dimensional shapes from flat patterns seeks to achieve similar objectives to patternmaking but with greater mathematical rigour. Sheet metal workers introduced many concepts that could blaze a path for Non-Euclidean geometry in patternmaking. While most of the techniques are not directly applicable, they offered inspirational ideas. Using simple-to-apply mathematics, making it all visual and easily manipulable by drafting diagrams, seem to be key.

Sheet metal working techniques are practical because the diagrams as drafted constitute an extremely accessible way of manipulating geometry. Mathematics in these equations is relatively simple and can be done with a calculator. One of the great challenges of working with both sheet metal and fashion patterns is manipulating curved shapes. Sheet metal workers have a technique for measuring complex shapes called "triangulation", whereby shapes can be simplified by dividing them into a series of smaller triangles (see figure 67, below). Such drafting techniques are hands-on and do not require computer calculations. To get accuracy on complex curves, a progressively greater number of progressively smaller triangles are used. If theoretically the number of triangles approached infinity the calculation of measurements should be exact (see figure 68). Triangulation closely resembles a mathematical process called a "limit", which is essential in a type of mathematics called "calculus". This fact inspired our research to combine mathematical techniques used in calculus into traditional fashion patternmaking.

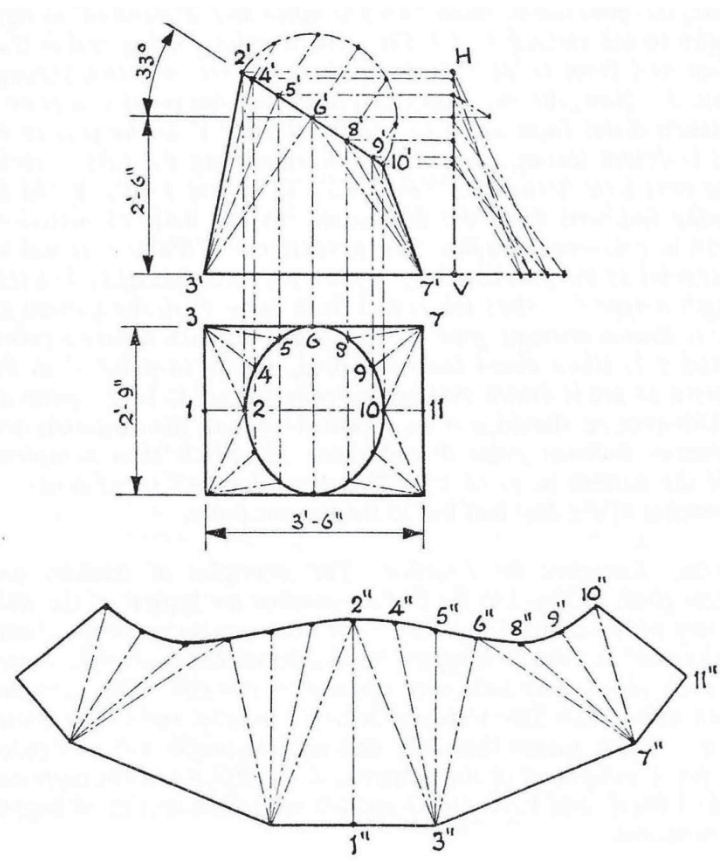


Figure 67: Triangulation techniques used by sheet metal workers turn complex 3D shapes into a series of triangles on a flat sheet metal pattern (Dickason 1967, p. 122).

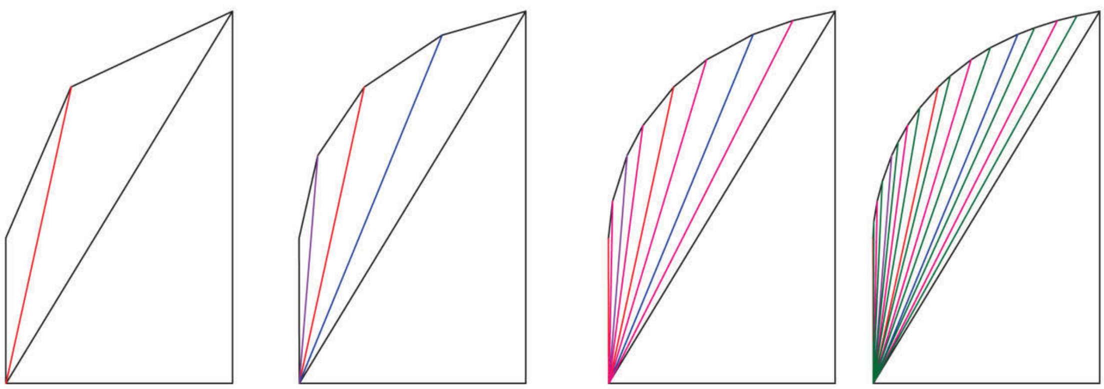
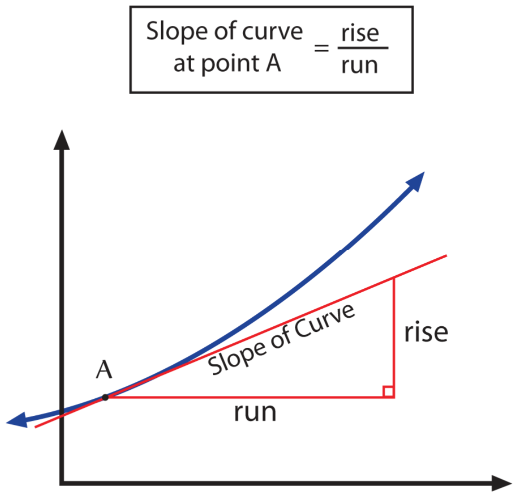


Figure 68: Triangulation technique deconstructs curved shapes into a series of triangles. The more triangles used to approximate the curve, the more accurate the pattern.

The significance of calculus

Calculus is one of the cornerstones of modern mathematics and science, and essentially allows us to measure the rates at which mathematical functions change over time. A key mathematical tool allowing engineers and scientists to develop technology in our modern world, it is extremely important in the study of geometry as it can be used to analyse curves and areas with great detail (Tabak 2004, p. 121). Ancient-world mathematicians such as Archimedes and Eudoxes explored techniques which came close to modern calculus, yet it is not until the 17th Century that Sir Isaac Newton and Gottfried Leibniz independently developed calculus (Tabak 2004, pp. 119 -122). This is where the ideas of “differential” and “integral” calculus were incubated, on the path to our modern mathematical language of calculus.

Ideas from calculus have significant potential applications in fashion patternmaking. Patternmaking is essentially about manipulating curved shapes, and calculus is a tool for more accurately measuring and manipulating these. While work with complex curved shapes is a great challenge even to highly skilled patternmakers, mathematical research over millennia has developed many strategies for working with such shapes. Calculus consists of two parts, namely “differential” and “integral”. The first has the ability to analyse complex curved shapes (see figure 69, below), and the second can measure the areas of curved shapes (see figure 70).



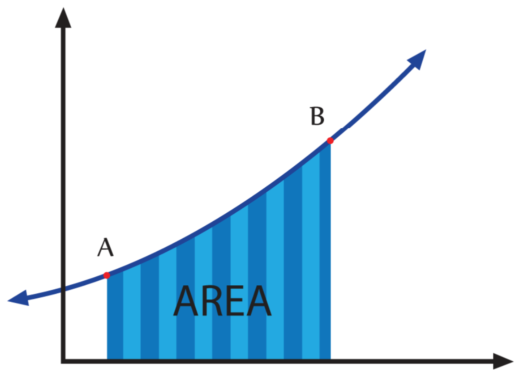


Figure 69:
Differential calculus can measure the properties of a point on a curve.

Figure 70:
Integral calculus can calculate the area under a curve.

These techniques can obviously be used to measure the curves and curved areas of pattern pieces. This in turn can test "manipulation" techniques, namely those which change the style lines on the pattern while keeping the same fit of the pattern. In turn, contour patternmaking is another technique that manipulates complex curved shapes to create curved three-dimensional patterns, and principles from differential calculus can help patternmakers manipulate these curves with greater precision.

For fashion designers, introducing calculus is a dilemma, since it is a skill most do not have. In mathematics, science and engineering, calculus is such an important tool that it is near-impossible to explain many concepts without it. In Non-Euclidean geometry many of the calculations used to find curved lengths and the area of surfaces require the use of calculus in their equations. In mathematics many principles offer rigorous proofs if we can understand the mathematics. Yet who can explain a mathematical idea to a patternmaker who does not understand the underlying mathematics? Calculus will have limited application in the fashion industry unless we can do exactly that.

In our research we have sought a way to explain sophisticated mathematical ideas such as calculus to fashion patternmakers with little knowledge of mathematics. Designers are often intimidated by complex equations with mathematical symbols (see figure 71, below), and many popular mathematics books try to simplify these ideas with limited success (see figure 72). Our research, in investigating the history of mathematics found that this form with symbols and numbers is a relatively new invention. Before the 17th Century geometry and diagrams were considered much more trusted forms of mathematical thought (Taimina 2009, p. 61). In fact, geometry was considered the most rigorous form of proof even for expressing concepts using numbers, and not until the 17th century did mathematicians place more emphasis on symbolic representations (Taimina 2009, p. 61). A new language of "symbolic algebra" emerged, which made manipulating and communicating ideas more efficient. Symbolic representation is normal fare for mathematicians, but geometry and visual diagrams can still offer great mathematical rigour. Designers can of course relate to diagrams much more easily. Thereby, to find a form of mathematics that is rigorous and can communicate visually, becomes of utmost importance.

$$\frac{df}{dt} = \lim_{h \to 0} \frac{f(t+h) - f(t)}{h}$$

Figure 71: A definition of differential Calculus.

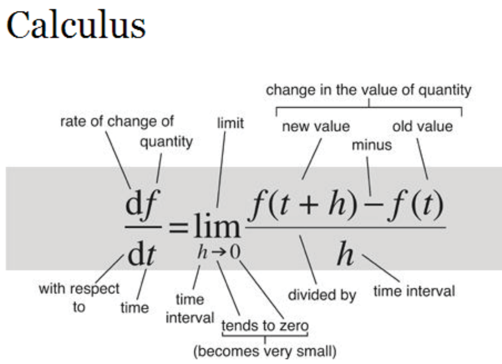


Figure 72: Diagram explaining what each of the symbols mean in a definition of differential calculus (Stewart 2012, p. 35).

Calculus 101 for fashion designers and patternmakers

We have seen that differential calculus can analyse the properties of curves while integral calculus can measure the area underneath complex curves (see figure 70). These tools are important in working with Non-Euclidean geometry, and our research took inspiration from calculus' ability to analyse complex curves in patternmaking. We began with a pre-calculus mathematical principle known as "The Trapezium Rule", a technique used to approximate the areas under a curve (see figure 73, below). This can be used to approximate how integral calculus works. It breaks the area under the curve into a series of small trapeziums to approximate the area under the curve (see figure 74). The smaller the width of the trapeziums, the more accurate the measurement. In theory, if these rectangles became infinitely small they would get very close to the exact size under the curve. In integral calculus the width of the rectangles approaches infinity, giving the exact area of the curve. This process of trapeziums approaching infinity uses the mathematical concept of a "limit", which is an easier way to explain how integral calculus works using visual communication.

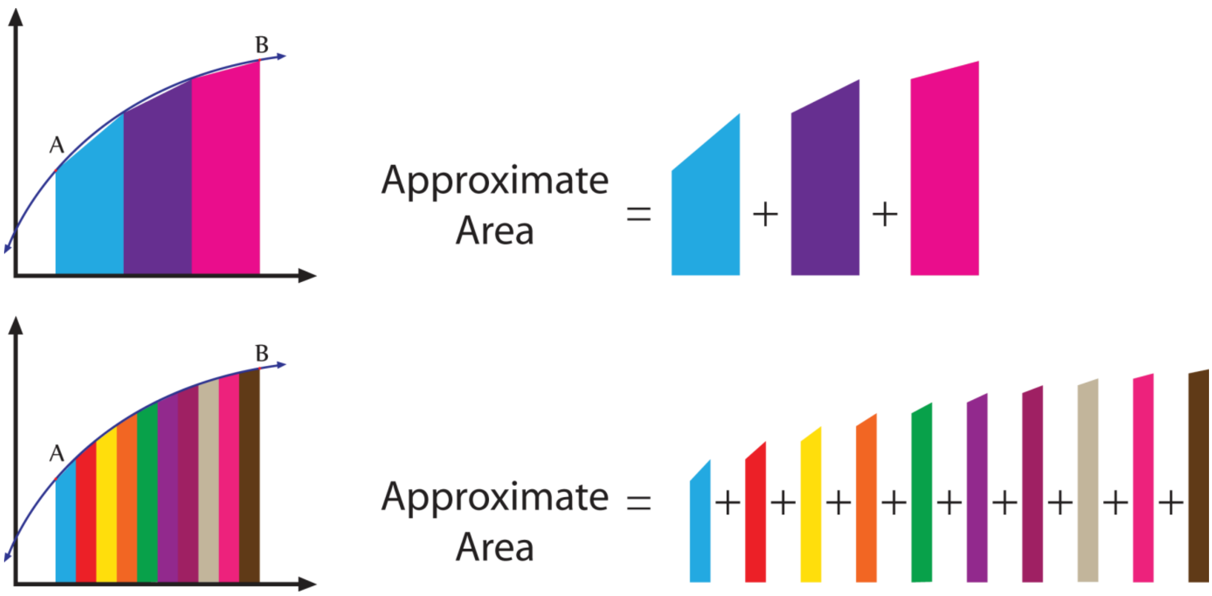


Figure 73: Trapezium rule.

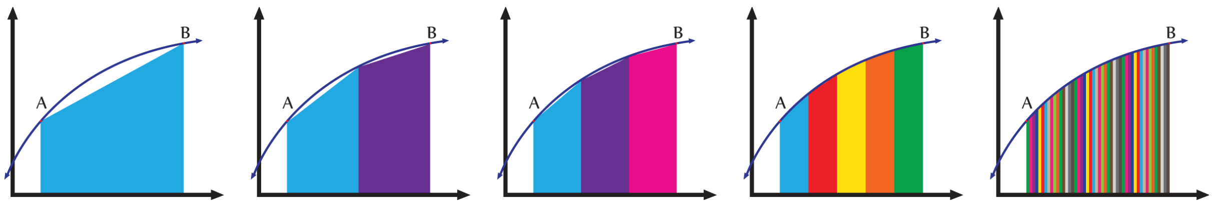


Figure 74: As the number of trapeziums increases, the more accurate the measurement becomes.

At first, the task of finding a visual proof for differential calculus seems overwhelming. Many students dread it because it is written in the “complicated” language of mathematics. The proof usually looks like that presented in figure 75, below. Even with an explanatory diagram the equation looks inaccessible (see figure 72). Our research sought to use a new type of mathematics called “Visual Calculus”, developed by mathematician Mamikon Mnatsakanian (2012). Mnatsakanian made the observation that differential calculus is essentially about finding the slope of a curve. This is measured by drawing a line that is a tangent to the curve and analysing the slope of this curve (see figure 76, below). Different points on a curved line all have different slopes, and these can be shown by drawing multiple tangents (see figure 77) whereby a curved line can be broken down into a series of tangent lines. This is useful for patternmakers as they are trained to very accurately draw tangent lines on patterns using a right-angled set square. Our research confirmed that patternmakers possess many skills in relation to these tasks. For example, using the patternmaker’s “rock of eye” to find the slope of a curve seemed the perfect intersection of patternmaking and calculus.

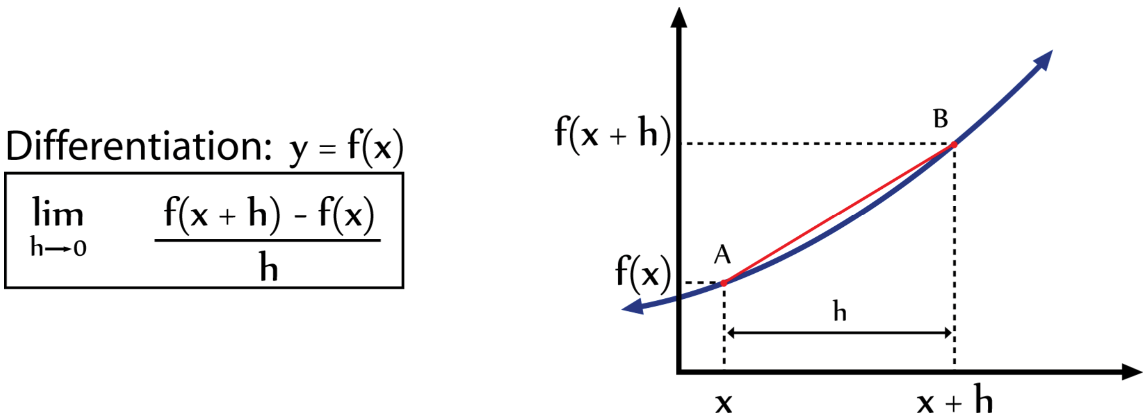
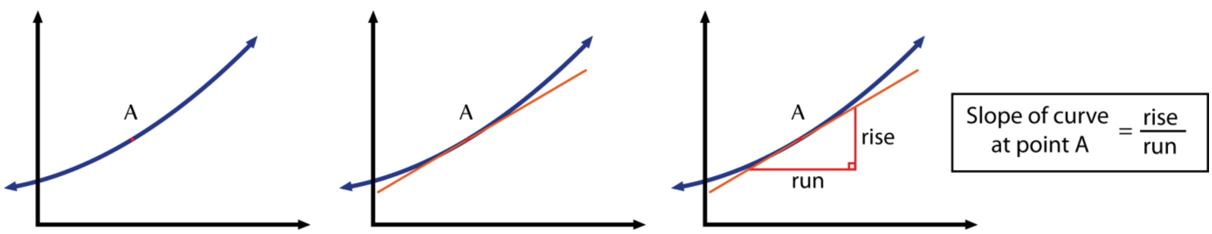


Figure 75: Diagram for differential calculus.



Differentiation is about finding the slope of a curve at point A.

The slope of the curve is the tangent at point A.

The slope of the tangent can be calculated.

Figure 76: Slope of the curve.

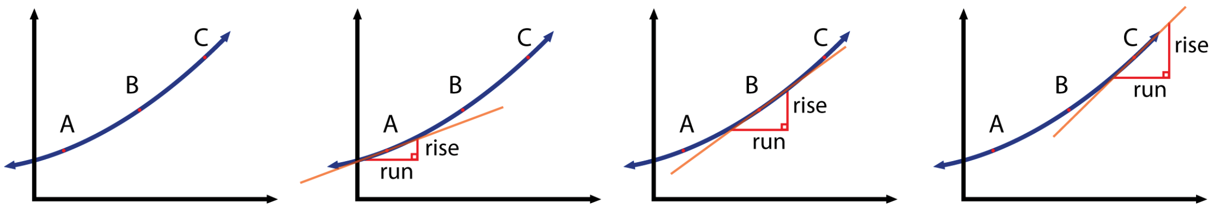


Figure 77: Different points on a curve can have different slopes.

In our research, we also needed to find a visual way to communicate the proof of differential calculus. Here, the goal is to try to find the slope of a line by finding a line which is drawn at a tangent to the curve (see figure 78, below). In this proof, in order to approximate the slope of the curve at point A, we take two points on a curve and draw a line between them. Point A is fixed, while point B is another point on the curve. The width between these points is called distance "h". As the size of the distance "h" becomes smaller, point B moves towards point A. This makes the slope of the line between A and B more accurately approximate to the slope of A. If the distance of "h" becomes so small that it approaches zero, the accuracy of the sloped line becomes the exact tangent to the line. This then, is the process of differential calculus described visually. While such proofs of calculus may seem overly technical for a thesis on fashion patternmaking, what matters is to convey the thought process. We must demonstrate different ways mathematicians use to break down complex forms to manageable equations. In fact, a line can be broken down into a series of sloped lines, and a complex area can be measured as the sum of a series of shapes. It is precisely this methodical approach which allowed mathematicians to analyse complex curves and shapes without being overwhelmed by them.

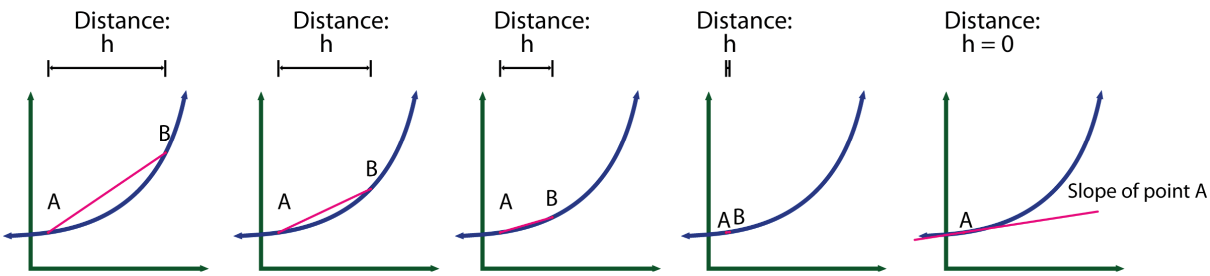
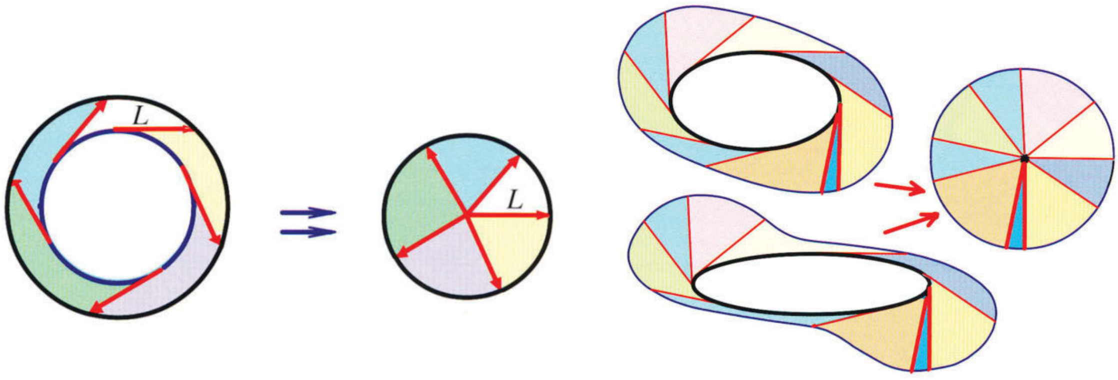


Figure 78: As the distance between point A and B decreases, the slope of the curve becomes more accurate. When distance h = 0 then the exact slope of point A has been found.

Our research investigated mathematics that uses the principles of calculus but does not require complex "symbolic representation". The less symbolic and mathematical language, the better it is for fashion patternmakers. In this vein, the research of mathematician Dr Norman Wildberger created an alternate system of trigonometry called "rational trigonometry" (Wildberger 2005). This system attempts to simplify trigonometry by removing the complex calculations created by calculus, irrational numbers and transcendental numbers. (These kinds of mathematics make equations complex and inaccessible to patternmakers.) Under Wildberger's system, trigonometry is reduced to manipulating algebra and arithmetic. The system offers simpler equations than regular trigonometry and may be attractive to fashion designers. However, it requires time and effort to re-learn all the principles of trigonometry. “Rational Trigonometry” is still too complex for fashion designers due to its emphasis on algebraic equations.

Application of visual calculus

Our research finally encountered the relatively new field of mathematics known as “Visual Calculus” developed by mathematician Mamikon Mnatsakanian (see figure 79). Apostol describes this field of research as “an innovative and visual approach for solving many standard calculus problems by a geometric method that makes little or no use of formulas” (Apostol & Mnatsakanian 2013, p. ix). Mnatsakanian’s visual diagrams managed to solve problems using geometry in an elegant “proof without words” (Apostol & Mnatsakanian 2013, p. ix). This work was first developed in 1959 when Mnatsakanian was an undergraduate student in Armenia. His approach to mathematics was inspired by the approach taken by Archimedes, who addressed complex mathematical proofs using simple geometric diagrams. At first, visual calculus was dismissed by Soviet mathematicians who said “It can’t be right. You can’t solve calculus problems that easily” (Apostol & Mnatsakanian 2013, p. ix). Yet the research would continue to evolve into a collection of mathematical papers published in prestigious mathematical journals, winning several mathematical awards. Visual Calculus is a relatively new area of research which may well make mathematics more tangible to fashion designers.



The area of the ring is the same as the circle.

These curved areas also have the same area as the circle.

Figure 79: Mnatsakanian discovered that the area of a ring between two concentric circles is the same area as a circle with the tangent length (L) at its radius. Using this principle, he is able to calculate the area of many different curved shapes (Mnatsakanian 2012, p. 7).

Visual calculus is remarkable in that it distils complex mathematical proofs to their essence, offering a way to solve problems using visual diagrams. This bypasses the need for complex mathematical equations and makes of them a practical tool. For instance, to find the derivative of a curve, we would need to find the equation of the curve and then use calculus to find the derivative. If the curve is complex, finding the equation will be difficult and completely impractical for the patternmaker. Mnatsakanian proceeds to distil differential calculus into a geometric problem. Finding the derivative is essentially about drawing a line that is a tangent to the curve (see figure 80, below). Mnatsakanian shows that whether we draw a line by hand or on a computer, it is possible to find the tangent point without explicitly calculating the slope of the point (Apostol & Mnatsakanian 2013, p. 14). For simpler curves he simply draws a line tangential to the curve (see figure 81). Mnatsakanian also offers more rigorous and concise proofs for this approach using visual diagrams (see figure 82). Here then is a practical way to find a derivative of complex shapes and curves without the need for complex calculation.

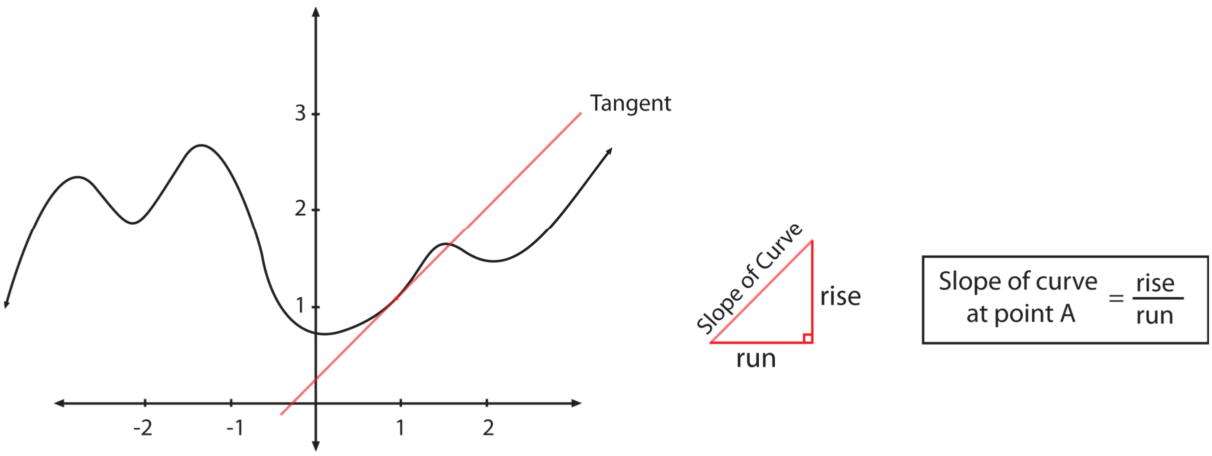


Figure 80: No matter how complex the curve or its equation, Mnatsakanian can find is derivative simply by drawing a tangent to the curve and measuring its slope.

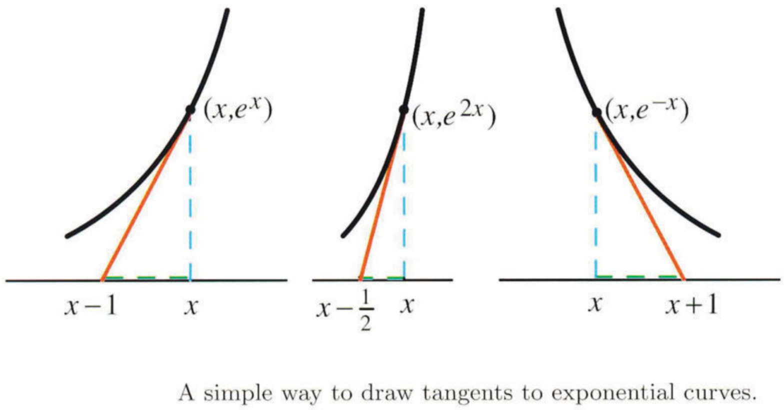


Figure 81: Mnatsakanian draws tangent lines to these curves to find their slope. Using geometry he finds answers which normally require differential calculus (Mnatsakanian 2012, p. 14).

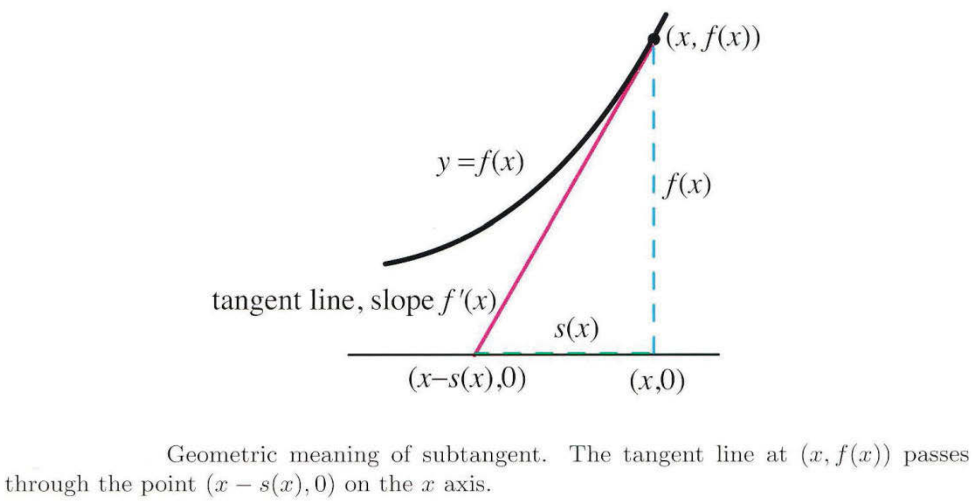


Figure 82: Mnatsakanian's mathematical definitions and proofs are visual and concise (2012, p. 15).

Visual calculus offers a completely different approach to integral calculus. Mnatsakanian's techniques are based on the discovery that by drawing tangent lines between two rings, the tangents can be re-arranged to form a circle (see figure 83, below). The circle and the ring shape have the same area. This process can be extrapolated to find the areas of complex curves. Mnatsakanian's "Tangent Sweep" technique is without doubt an innovative way to solve problems in integral calculus without the need for complex calculations (see figure 84). He creates this "tangent sweep" by drawing tangent lines between two curves in order to measure their area. These tangents can then be re-organised into a "tangent cluster" which forms the sector of a circle. Essentially, this is a way of taking a complex shape, breaking it into pieces and then re-organising it into a shape that is easier to measure (see figure 85). Mnatsakanian developed many variations of this technique, including tangent sweeps that can have variable lengths (see figure 86, below). These techniques can be applied to measure the areas of complex shapes.

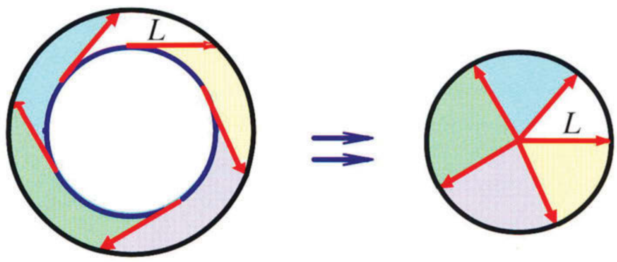


Figure 83: Mnatsakanian theorems are derived from the idea that the area of a ring is the same as a circle with the tangent as its radius (Mnatsakanian 2012, p. 7).

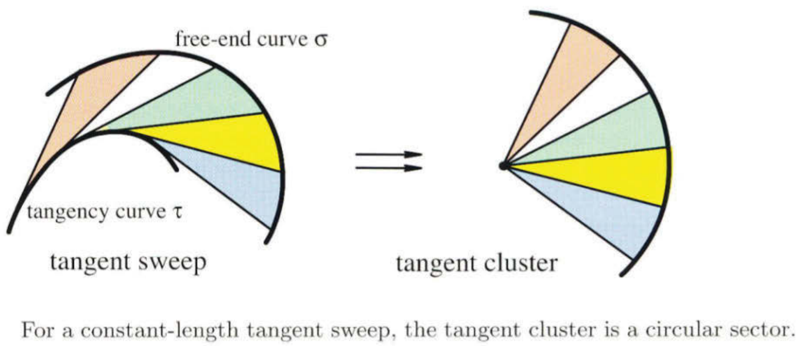


Figure 84: The "tangent sweep" technique is a way of finding the area between two curves by finding the tangent cluster which has the same area (Mnatsakanian 2012, p. 11).

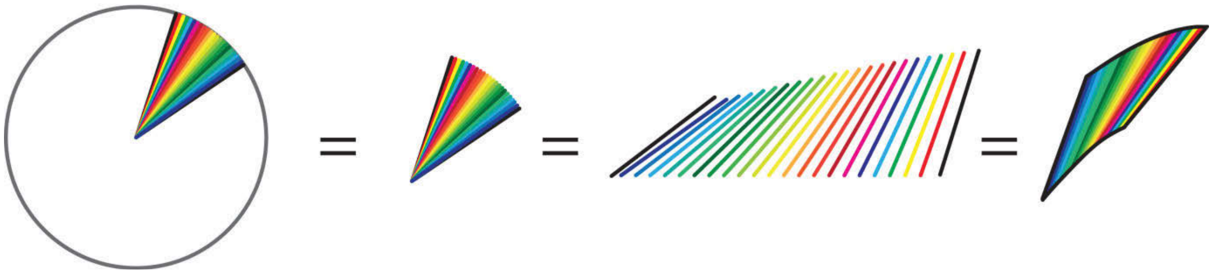


Figure 85: Mnatsakanian's technique essentially uses geometry to divide simple shapes into tiny pieces, then re-arrange them into more complex shapes.

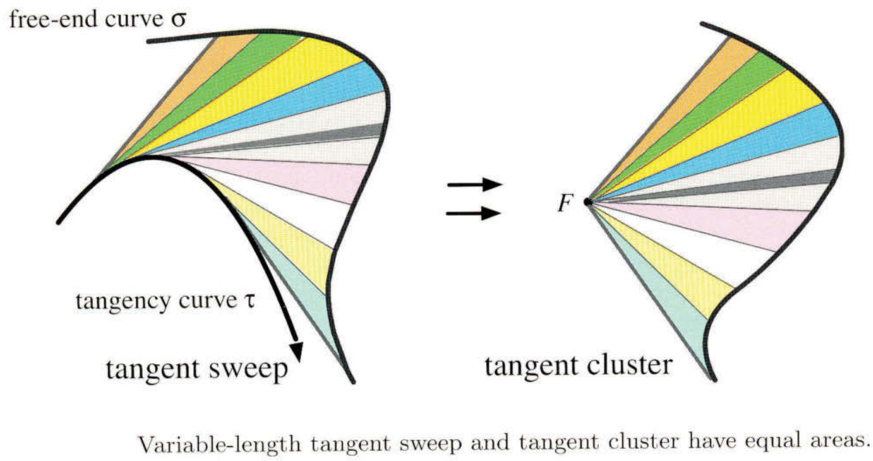


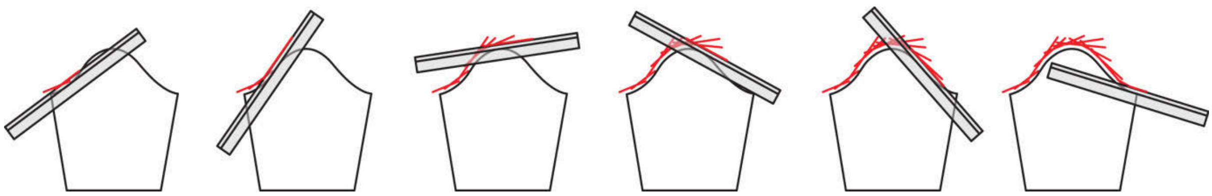
Figure 86: Mnatsakanian developed tangent sweeps which can have variable lengths (Mnatsakanian 2012, p. 12).

Visual calculus avoids many complex calculations, it is possible to visually check that the equations are working. To manually calculate curved areas appears to be difficult, yet if the areas are deconstructed into small triangles reconstructed into a simpler shape, the solution seems easier. We are reminded of the technique of triangulation used by sheet metal workers, in effect an extremely practical way of working with complex shapes. Mathematicians use idealised proofs built on pure logic and do not have to rely on physical phenomena, whereas patternmakers appreciate ideas that are practical and can be physically demonstrated. Visual calculus offers mathematical rigour yet is hands-on enough to be a useful tool for patternmakers. This is the kind of thinking our research needs, in developing more accurate patternmaking techniques.

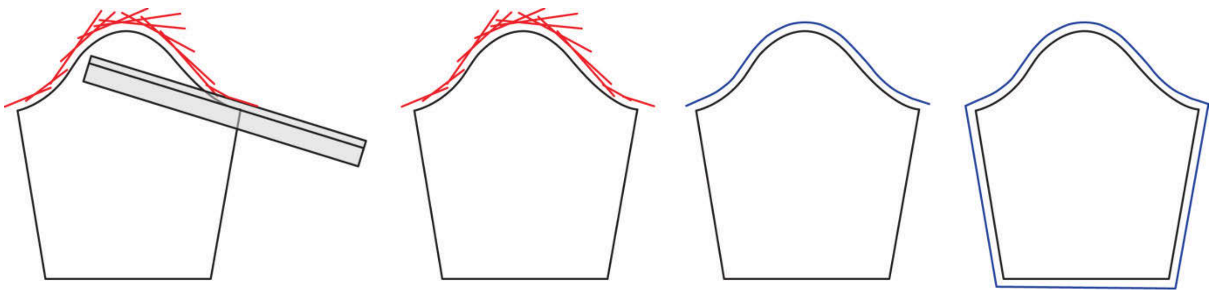
Non-Euclidean geometry and visual calculus combined, make applying mathematics to patternmaking far more practical. Non-Euclidean geometry alone would be a set of principles applicable only to idealised geometric shapes. Again, this is because in order to make accurate calculations we need to know the equations of all the curves and three-dimensional forms. In reality the shapes used in fashion patternmaking are complex, and finding the equations of these shapes without a computer is completely impractical. Yet when combined with principles of visual calculus, it is now possible to analyse complex curves and areas without knowing the equations of these curves. Complex curves can be easily analysed using simple drafting techniques. Visual calculus has inspired our research to transpose concepts from Non-Euclidean geometry into practical techniques for fashion patternmaking.

Patternmakers' unconscious mathematical skills

Our research has considered whether patternmakers have the skill to integrate more complex mathematical ideas into their work. We have seen how Mnatsakanian used visual calculus to turn complex calculus techniques into a simple geometric problem, whereby in differential calculus we draw a tangent to a curved line. We asked whether a patternmaker could implement this process. Can they understand a tangent and be able to accurately draw this line on a curve? We observe that patternmakers are skilled at drawing seam allowances on complex curved shapes (see diagram 87, below). When a patternmaker draws a seam allowance on a curved shape such as a sleeve he takes a ruler and draws tangents to the curved line. He draws so many of these that they join together to make a smooth line. Patternmakers actually use a mathematical skill without realising it, in that drawing a tangent to a curved line is the same process Mnatsakanian uses in his visual calculus. Key to the accuracy of the process is drawing an accurate tangent line, and a patternmaker has the skill and muscle memory to draw extremely accurate tangents. Patternmakers can thereby harness their drafting skills to apply complex mathematical techniques that enhance their practise.



Patternmakers are adept at putting tangents on curves in order to draw curved seam allowances.



Patternmakers use rulers to draw curved seam allowances. A series of tangent lines makes up a curved seam allowance. This can be drawn into a smooth curved line. Seam allowances are drawn around the entire pattern.

Figure 87: When patternmakers draw curved seam allowances with a ruler they are actually drawing tangents to the curve.

Integral calculus is the mathematics whereby we measure the areas of curved shapes. With visual calculus Mnastakanian is essentially deconstructing complex shapes into simpler pieces and figuring out ways to measure them. Our research has noted patternmaking concepts similar to this concept. “Grading” is a technique familiar to all patternmakers. Some grading processes require them to cut the pattern into smaller components so that they can be scaled up in size (see figure 88, below). This process requires them to deconstruct a complex shape into rectangles and simple curves shapes, and actually allows the area of the object to be easily calculated. Here is another instance of how patternmakers unconsciously possess some of the skills required to wield powerful mathematical ideas.

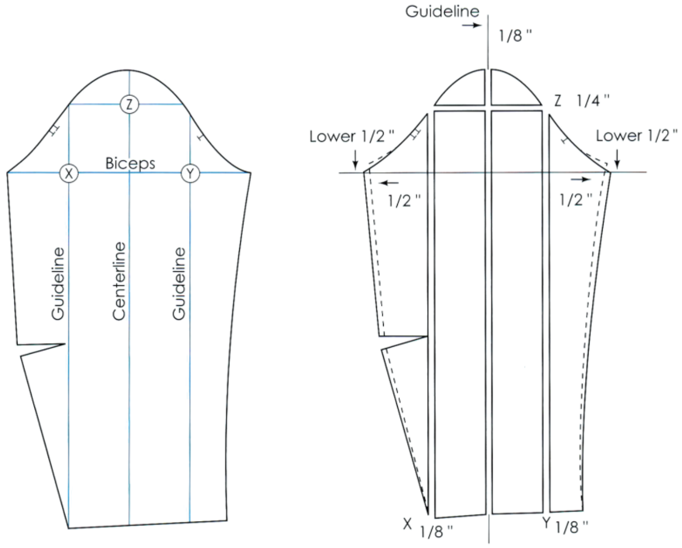


Figure 88: Patternmakers are proficient at deconstructing patterns into different shapes, and use this skill when scaling patterns (Armstrong 2010, p. 462).

What can fashion patternmakers learn from mathematics?

The research in this thesis has posited several key concepts from mathematics that can be applied to fashion patternmaking. Principles of limits, triangulation and calculus demonstrate that complex shapes can be deconstructed into smaller pieces, whereby these pieces are easier to measure and manipulate. Mathematicians have been shown to take overwhelmingly complex problems and turn them into simpler ones. In general, this process is relevant for patternmaking in the deconstruction of complex curves or manipulated curved areas. The ability to accurately measure these properties is an important new tool in patternmaking.

The history of mathematics offers many examples of how the application of mathematical principles to a traditional craft can lead to rapid technological advancement. Principles from Non-Euclidean geometry reveal to us that when existing patternmaking systems are based on assumptions from Euclidean geometry, this limits their accuracy and creates systemic problems for patternmakers. Such problems extend to fashion technologists who automate traditional techniques into three-dimensional scanning technology. Our research has identified the need to create a patternmaking system based on modern mathematical principles, and that a modern patternmaking system should benefit from the ideas of Non-Euclidean geometry while still fulfilling the needs of the traditional patternmaker. In short, our research consistently bridges the gap between traditional patternmaking and modern mathematics.

EXPERIMENTS

Investigating Darts, Gussets and Contours with modern geometry.

Re-Evaluating Traditional Techniques with modern geometry.

Creative patternmaking inspired by modern geometry.

Non-Euclidean Patternmaking.

Mapping Movement.

Variable Structures.

EXPERIMENTAL ROADMAP

Investigating Darts, Gussets and Contours with modern geometry:

1: Darts

1: The properties of dart apex points	2: Dart manipulation and dart leg symmetry	3: Total angles in dart manipulation	4: Dissecting cones

2: Gussets

5: Gusset manipulation	6: Total angles in gusset manipulation	7: The shape of gussets after gusset manipulation	8: A comparison of the properties of darts and gussets

3: Complex Darts

9: Complex darts: diamond darts	10: Concave and convex darts	11: Concave and convex gussets	12: Designing on complex darts

4: Contour Manipulation

13: Contour manipulation part 1	14: Contour manipulation part 2	15: Designing on contours

5: Asymmetrical Darts and Gussets

16: Asymmetrical darts	17:Symmetrical and asymmetrical darts	18: Asymmetrical gussets	19: Curved contour lines in contour manipulation

Re-Evaluating Traditional Techniques with modern geometry:

6: Exploring Traditional Bust Point Manipulation

20: Testing dart angles of traditional bust point dart manipulation	21: Surface area of traditional bust point dart manipulation	22: Using geometry to show a change in surface area

7: Moving Dart Apexes

23:What happens when we move the apexes of darts	24: Calculating the tilt of a cone when an apex is moved	25: Measuring cone tilt at bust point manipulation	26: The effect of moving apexes of darts	27: The effect re-drawing contours, moving the apexes of darts

8: Re-Evaluating Traditional Bust Point Manipulation

28: Re-evaluating bust point dart manipulation	29: An alternative approach to fitting a bust point dart	30: An alternative approach to bust point dart manipulation	31: Testing cone tips of different shapes	32: An alternative method for bust point manipulation with multiple darts

Creative patternmaking inspired by modern geometry:

9: Creative Patterns Inspired by Geometry

33: Achieving more	34: Achieving greater	35: Greater creative	36: Modifying patternmaking

<table>
<tr><td>creative patterns using geometry</td><td>complexity with more apex points</td><td>freedom with fewer apex points</td><td>and drape techniques for easier patternmaking</td></tr>
<tr><td colspan="6">10: Exotic Darts</td></tr>
<tr><td>37: “V” and heart darts</td><td>38: Branching darts</td></tr>
<tr><td colspan="6">11: Reshaping Darts and Contours</td></tr>
<tr><td>39: Re-shaping contours and moving dart apexes</td><td>40: Creating elliptical cross-sections to move apex points</td></tr>
<tr><td colspan="6">12: Wrinkle Analysis</td></tr>
<tr><td>41: Wrinkle analysis part 1</td><td>42: Wrinkle analysis part 2</td></tr>
<tr><td colspan="6">Non-Euclidean Patternmaking:</td></tr>
<tr><td colspan="6">13: Measuring Non-Euclidean Measurements</td></tr>
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<tr><td colspan="6">Mapping Movement:</td></tr>
<tr><td colspan="6">15: Mapping Body Movement Using Flat Patterns</td></tr>
<tr><td>52: Recording body movement as flat patterns</td><td>53: Learning from movement</td><td>54: Mapping bend joints</td><td>55: Mapping rotational joints</td><td>56: Mapping the hip joint</td></tr>
<tr><td>57: Mapping the shoulder shrug</td><td>58: Mapping the deltoid</td><td>59: Sitting down is complex</td><td>60: A summary of the range of motion</td></tr>
<tr><td colspan="6">16: Questioning the Current Paradigm of Fit</td></tr>
<tr><td>61: Questioning the current paradigm of fit</td><td>62: A new paradigm of fit</td><td>63: Alternate strategies to fit</td></tr>
<tr><td colspan="6">Variable Structures:</td></tr>
<tr><td colspan="6">17: Variable Darts</td></tr>
<tr><td>64: Variable structures</td><td>65: Variable darts</td><td>66: Exploring the properties of oblique cones</td><td>67: Programming the interaction of variable darts</td></tr>
<tr><td>68: Using variable structures to design garments</td><td>69: Using oblique cones in variable darts</td><td>70: The control points of a variable dart</td><td>71: Different configurations of variable darts</td></tr>
<tr><td colspan="6">18: Variable Structures</td></tr>
<tr><td>72: Singularities</td><td>73: Wormholes</td><td>74: Floating plates</td><td>75: Smart garments</td><td>76: A network</td><td>77: The piston</td></tr>
</table>

Figure 1: Experimental Roadmap.

EXPERIMENTS

1. Darts

Experiment 1: **The properties of dart apex points**

Experiment 2: **Dart manipulation and dart leg symmetry**

Experiment 3: **Total angles in dart manipulation**

Experiment 4: **Dissecting cones**

Aim

This group of four experiments explores the properties of darts, which are shapes sewn out of fabric that alter the three-dimensional form of a garment. A series of experiments investigates the properties of dart apex points, dart angles, dart manipulation and the dissection of darts into cones.

Method

The first experiment explores the properties of the dart apex point by flattening different dart patterns. The second investigates dart manipulation and the process whereby different-shaped style lines can be created while maintaining the geometric form of the original garment. The third experiment explores the total dart angles of a pattern when a dart is divided into a larger number of darts, while the fourth views a dart as a cone and dissects it into a series of smaller cones.

Analysis

These experiments illustrate the importance of the dart apex point and how its angle determines the shape of the dart. Darts significantly change the geometry of a garment. Their properties can be best explained by viewing them as cones. In dart manipulation a seam line of any shape can be created by cutting the line from the dart apex to the edge of the cone. This in effect changes the location of the seam line while maintaining the original 3D form of the cone. It is noted that darts maintain the same total of dart angles even if they are cut into smaller darts. This has the same effect as taking a cone and cutting multiple style lines from the cone apex to the edge of the cone. The cone can then be flattened into a series of darts, while the cone will always maintain the sum of total angles. Darts can also be cut into smaller parts that maintain the same type of geometry. For example, a cone can be cut horizontally to create a smaller cone on the tip, and to create shapes called “frustums”. These constitute the base of a cone and present the same geometric properties as the cone they derive from.

Experiment 1: The Properties of Dart Apex Points

Rationale

This experiment observes the geometric properties of the apex points of darts. This is achieved by flattening three-dimensional paper models into flat patterns. It tests if it is necessary to cut a line from the edge of the pattern to the dart apex point in order to flatten the pattern. The experiment demonstrates the importance of dart apexes in fashion patternmaking. Paper models are chosen as they do not stretch, preserving the geometry of the pattern.

Hypothesis

The research anticipates that darts used by fashion patternmakers should have the same geometric properties as cones. It should only be possible to flatten a three-dimensional dart pattern if a line is cut to its apex point.

Experimental Design

The experiment is designed to investigate the process of flattening a three-dimensional pattern into a flat pattern. It examines whether it is necessary to cut a line from the edge of a pattern to the dart apex point in order to flatten the pattern. Paper models which have been cut to apex point are compared with models that have not been cut to dart apex point. It tests if it is possible to flatten a pattern if a line is not cut to apex point. This idea is analysed through two sets of experiments.

Procedure

In order to maintain consistency, each of the paper models is constructed in the same way. The paper patterns are created from identical copies of a standard dart block. They are printed from the same digital file on 80 gsm paper. The paper models are carefully cut out and assembled using tape to create a three-dimensional model (see figure 1).

Set 1:

Construct four identical paper models of a block dart pattern.

Each one of these models will be cut and flattened in a different way:

Model 1: Leave as the original pattern.

Model 2: Cut from the edge of the pattern to a point above apex point.

Model 3: Cut from the edge of the pattern to a point near the apex point.

Model 4: Cut to apex point.

Compare these patterns and make observations.

Set 2:

Construct four identical paper models.

Each one of these models will be cut and flattened in a different way:

Model 5: Leave as the original flat pattern.

Model 6: Construct the original pattern in three dimensions.

Model 7: Cut down the line on the side of the pattern to a point near the apex point.

Model 8: Cut from the edge of the pattern to the apex point.

Compare these patterns and make observations.

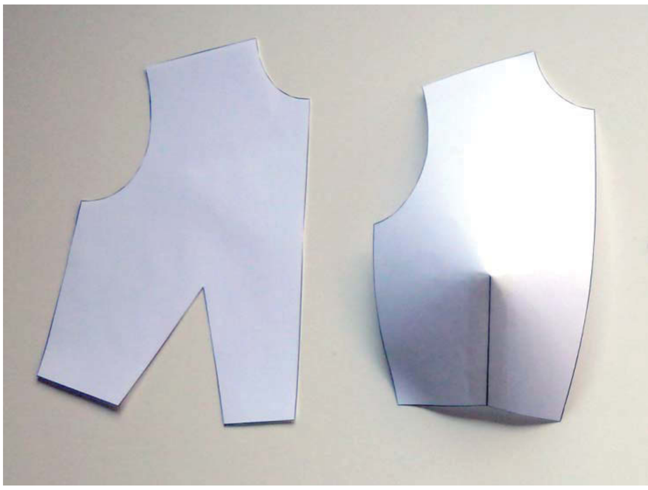
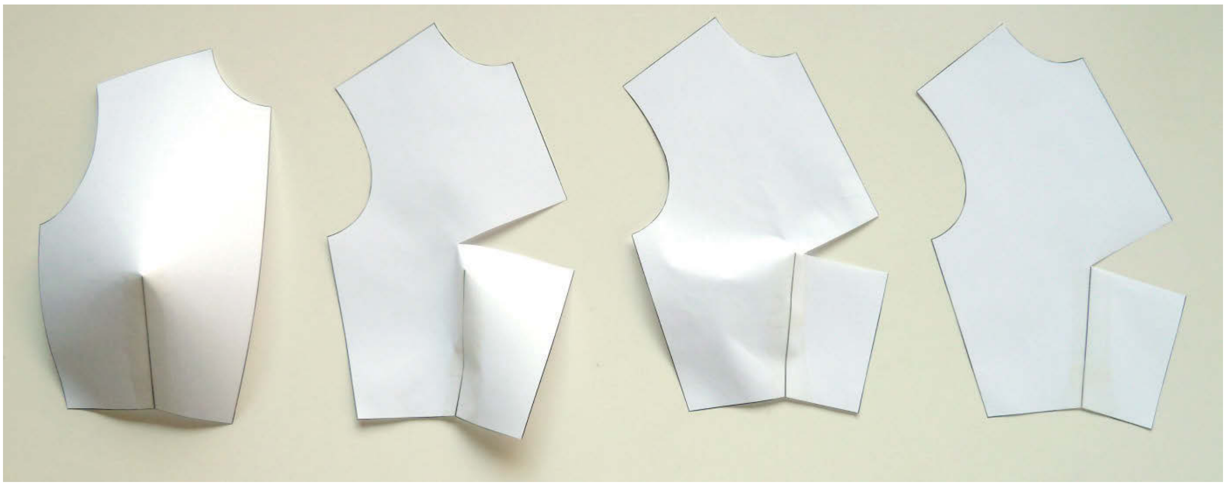


Figure 1: A basic block pattern with a dart as a flat pattern, and as a three-dimension model.

Results

Set 1:

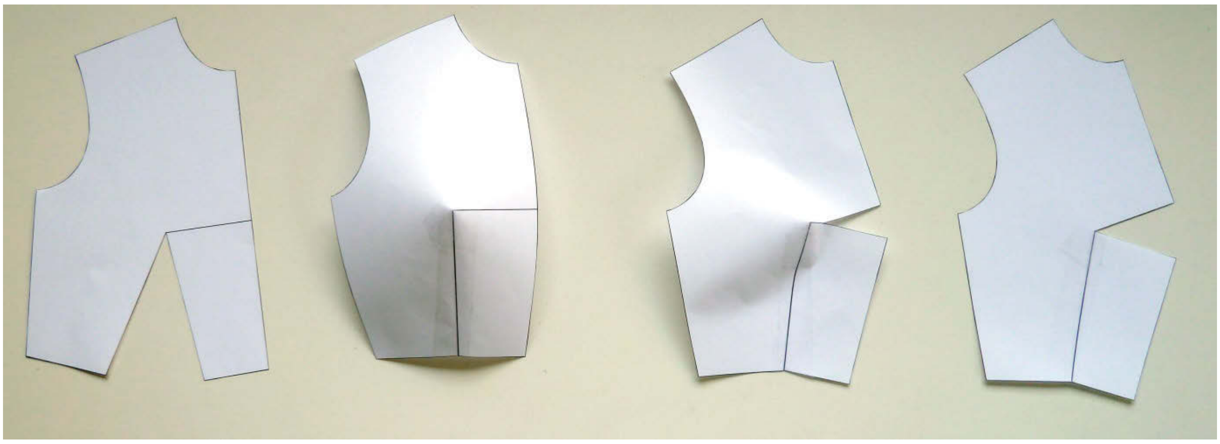


Model 1: Original 3D pattern:	Model 2: Pattern cut past apex:	Model 3: Pattern cut near the apex:	Model 4: Pattern is cut to the apex:
The original pattern is left as a control.	The cut did not pass through the apex so it could not be flattened.	The cut did not pass through the apex so it could not be flattened.	This pattern could be fully flattened.

Figure 2: Flattening a three-dimensional dart pattern into a flat pattern.

The results show that the only pattern that can be fully flattened is the model cut to the apex point (model 4). Model 1 is used as a control and cannot be flattened. Models 2 and 3 can only be partially flattened. Both of these models are cut close to the apex point, but never pass through it. It is observed that the closer a pattern is cut to the apex point; the easier it is to flatten the pattern. Model 4 is the only pattern that can be fully flattened.

Set 2:



Model 5:	Model 6:	Model 7:	Model 8:
Original Flat pattern.	Original 3D pattern.	3D pattern cut near the apex.	3D pattern is cut to the apex.

Figure 3: Flattening a three-dimensional dart pattern into a flat pattern.

The results show that the only patterns that can be fully flattened are the models cut to apex point. Model 5 is the original flat pattern and its dart is cut to apex point. Model 6 is a control and is not flattened. Model 7 is only partially cut to the apex point and therefore cannot be fully flattened. Model 8 is cut all the way to the apex point and can be flattened.

Conclusion

This experiment demonstrates that it is not possible to fully flatten a dart pattern without cutting a line to its apex point. Dart patterns that are not cut through the apex point of a dart can only be partially flattened. This shows how important the location of the dart apex is in the structure of a dart.

Experiment 2: Dart Manipulation and Dart Leg Symmetry

Rationale

This experiment observes the geometric properties of dart manipulation, a process where the seam line or "style line" of a dart is moved around a pattern while retaining the garment's three-dimensional shape. It explores the properties of style lines from simple straight lines to complex curved lines. One of the aims of the experiment is to see with what complexity the darts can be made without losing the accuracy of the original pattern. The ability to draw a style line of any shape serves functional and aesthetic purposes. The experiment explores the symmetry of the style lines as the patterns are manipulated.

Hypothesis

The research anticipates that darts that have undergone dart manipulation should have the same dart angles. The shapes of the style lines should also have rotational symmetry.

Experimental Design

The experiment tests the properties of a basic dart block that is manipulated with many different types of style lines. It starts by manipulating a simple straight line, and increases the complexity of the style lines into curved lines. The experiment creates five sets of models that each test a different type of style line. Set 1 tests dart manipulation with straight lines, while Set 2 explores the drawing of simple curved style lines. Set 3 experiments with drawing freehand curved lines from the edge of the style line, and Set 4 creates spiral style lines. Set 5 creates double-spiral style lines. In sum, these experiments aim to carefully observe the properties of the dart legs.

Procedure

All models in this experiment start with the same basic dart block (see figure 1). Style lines of different shapes are then drawn on the surface. To ensure that the style lines are on the same location in each of the patterns, the lines are drawn onto the digital file and identical copies are printed on 80 gsm paper. The patterns are assembled into three-dimensional models using tape.

The properties of the style lines are tested in five sets of models:

Set 1: Straight style lines

Construct paper models using the same basic dart block.

Model 1: Leave as the original flat pattern.

Model 2: Construct the original pattern in three-dimensions.

Model 3: Draw a straight style line from the apex to the right edge of the pattern.

Model 4: Cut through the new style line on the pattern.

Model 5: Flatten the pattern.

Observe the three-dimensional and flat patterns created by the dart manipulation.

Set 2: Curved style lines

Construct paper models using the same basic dart block.

Model 6: Leave as the original flat pattern.

Model 7: Construct the original pattern in three-dimensions.

Model 8: Draw a curved style line from the apex to the right edge of the pattern.

Model 9: Cut through the new style line on the pattern.

Model 10: Flatten the pattern.

Observe the three-dimensional and flat patterns created by the dart manipulation.

Set 3: Freehand style lines

Construct paper models using the same basic dart block. Draw a wavy line from the apex point to the edge of the pattern.

Model 11: Draw a freehand style line on the flat pattern.

Model 12: Cut down the style line and flatten the pattern.

Trace the edge of the dart style line on the flat pattern and rotate it to see if the dart has rotational symmetry.

Construct paper models using the same basic dart block. Draw a style line consisting of curves and straight lines from the apex point to the edge of the pattern.

Model 13: Draw a freehand style line on the flat pattern.

Model 14: Cut down the style line and flatten the pattern.

Trace the edge of the dart style line on the flat pattern and rotate it to see if the dart has rotational symmetry.

Set 4: Spiral style lines

Construct paper models using the same basic dart block.

Model 15: Leave as the original flat pattern.

Model 16: Construct the original pattern in three dimensions.

Model 17: Draw a curved spiral style line from the apex to the edge of the pattern.

Model 18: Cut through the new style line on the pattern.

Model 19: Flatten the pattern.

Observe the three-dimensional and flat patterns created by the dart manipulation.

Set 5: Double spiral style lines

Construct five paper models using the same basic dart block. For models 22 to 24 draw a spiral line from the apex point to the edge of the pattern.

Model 20: Leave as the original flat pattern.

Model 21: Construct the original pattern in three-dimensions.

Model 22: Draw two sets of curved spiral style lines from the apex to the edge of the pattern.

Model 23: Cut through the new style line on the pattern.

Model 24: Flatten the pattern.

Model 25: Trace the outline of two pattern pieces created in model 24. This helps to show the two different patterns created from cutting a double spiral pattern.

Observe the three-dimensional and flat patterns created by the dart manipulation.

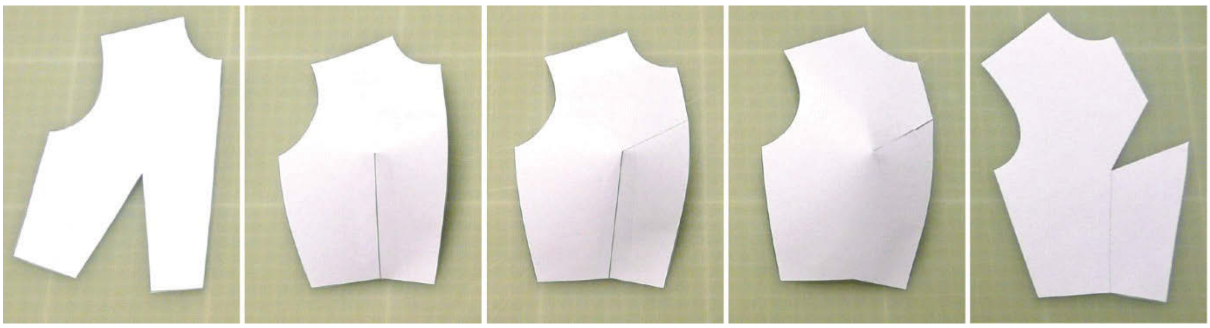
Flat pattern

3D Pattern

Figure 1: The basic dart block pattern.

<u>Results</u>

Set 1: Straight style lines



Model 1: Flat pattern.

Model 2: 3D pattern.

Model 3: Draw a new straight line on the pattern.

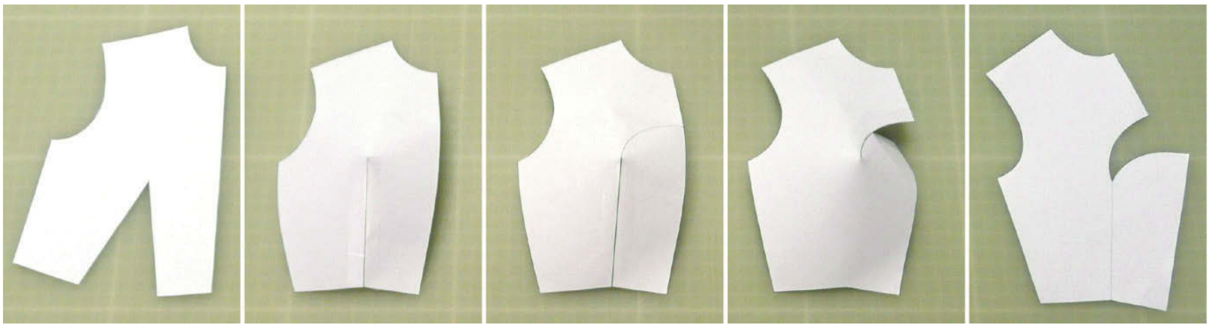
Model 4: Cut through the new style line.

Model 5: A flat pattern is created with new dart location.

Figure 2: Drawing a new style line and cutting down that line creates a new pattern that is geometrically equivalent to the original pattern.

It is observed that the flat pattern of the original pattern (model 1) has an angle measurement of 37°, the same dart angle as the manipulated pattern (model 5). The dart leg of the original pattern has rotational symmetry as they are both straight lines (model 1). The final manipulated pattern also has rotational symmetry since both dart legs are also straight lines (model 5).

Set 2: Curved style lines



Model 6: Flat Pattern.

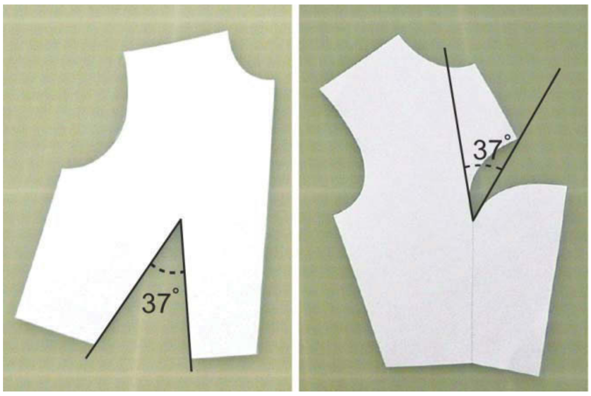
Model 7: 3D Pattern.

Model 8: Draw a new curved style line on the pattern.

Model 9: Cut through the new style line.

Model 10: A flat pattern is created with new curved dart.

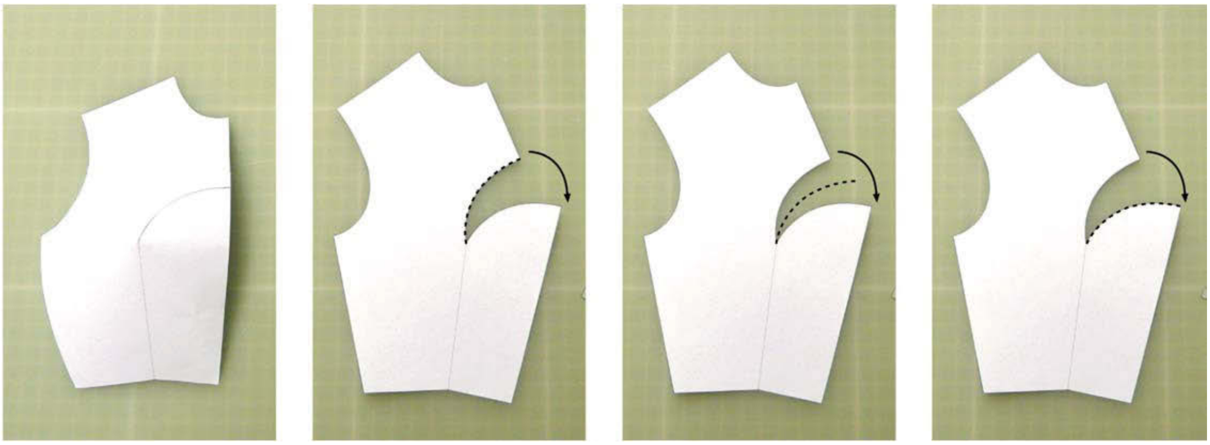
Figure 3: The curved dart. Drawing a curved line from the apex of the basic block and cutting down that line creates a new pattern that is geometrically equivalent to the original pattern.



Model 6: Dart angle of original pattern.

Model 10: Dart angle of curved pattern.

Figure 4: The original pattern and the curved dart have the same dart angle.



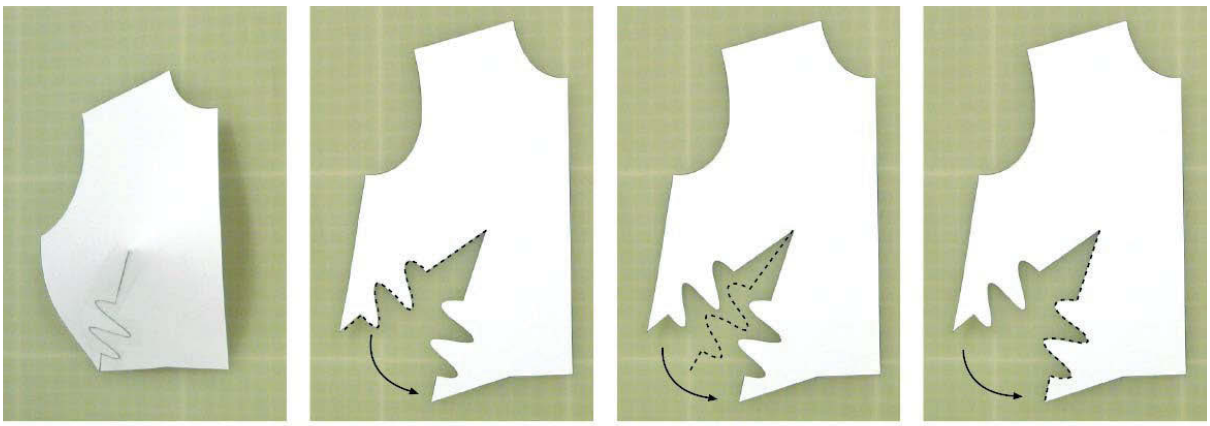
Model 8:
Draw a curved style line on
the three-dimensional pattern.

Model 10:
Cut down the style line and flatten the pattern.
Trace the shape of the style line and rotate it to see if the pattern has rotational symmetry.

Figure 5: The curved dart leg has rotational symmetry. This can be demonstrated by tracing the curve of one dart leg and rotating it to match the other dart leg.

It is noted that creating curved style lines with dart manipulation has similar properties to dart manipulations with straight lines (figure 3). Figure 4 demonstrates how the dart angle of the curved style line and the original dart pattern are the same. Figure 5 also illustrates how the new curved dart pattern has rotational symmetry. This means that the shape of the curved edge is the same when rotated around the apex point.

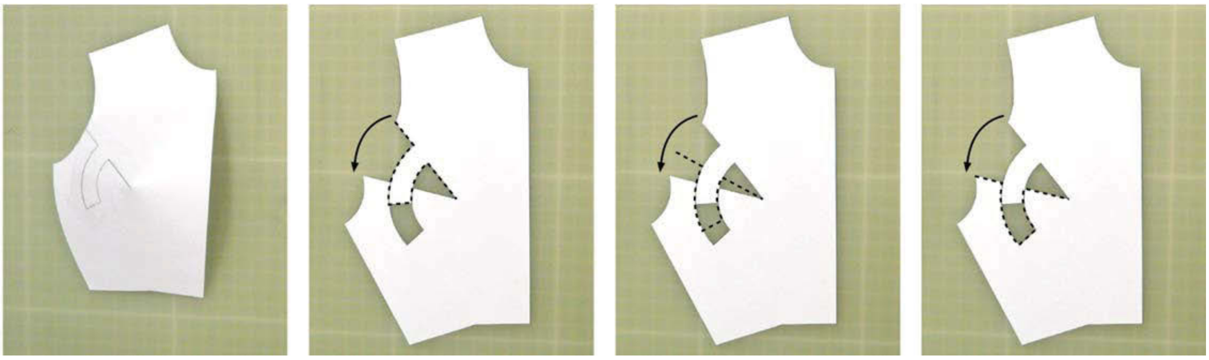
Set 3: Freehand style lines



Model 11:
Draw a wavy style line on
the three-dimensional pattern.

Model 12:
Cut down the style line and flatten the pattern.
Trace the shape of the style line and rotate it to see if the pattern has rotational symmetry.

Figure 6: This style line with a wavy shape can be rotated to match the opposite dart leg. This shows it has rotational symmetry.



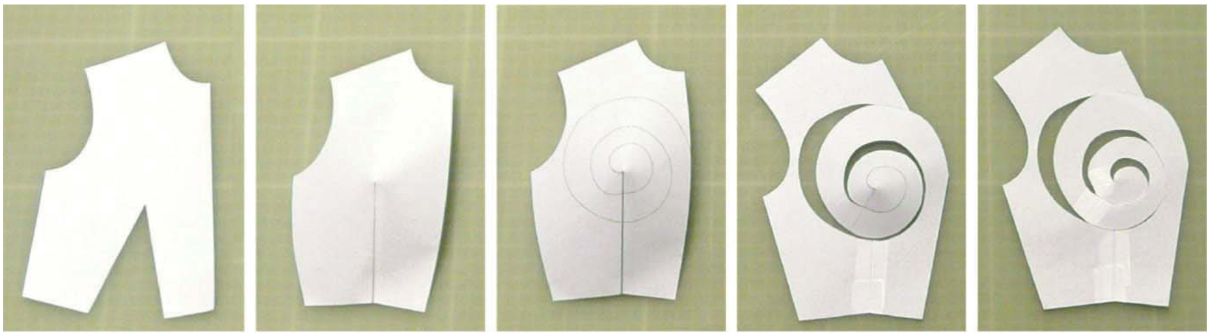
Model 13:
Draw a style line with a combination of straight and curved lines on a three-dimensional pattern.

Model 14:
Cut down the style line and flatten the pattern.
Trace the shape of the style line and rotate it to see if the pattern has rotational symmetry.

Figure 7: This style line with straight and curved shapes can be rotated to match the opposite dart leg. This shows it has rotational symmetry.

These experiments test the ability of patternmakers to draw complex freehand curves as style lines. Patternmakers can draw any shape they like as long as the pattern starts at the apex and reaches the edge of the pattern. These experiments are used to test if there is any limit to the complexity of the curves that can be created. In both figure 6 and figure 7 the patterns maintain their properties of rotational symmetry.

Set 4: Spiral style lines



Model 15: Flat Pattern.

Model 16: 3D pattern.

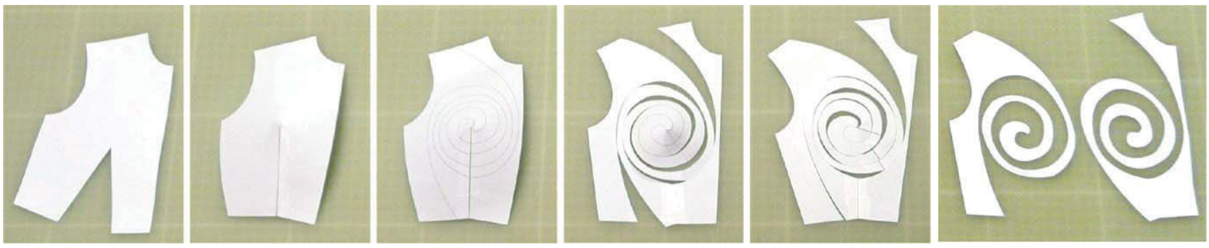
Model 17: Draw a curved spiral style line on the pattern.

Model 18: Cut through the new style line.

Model 19: Flatten the pattern.

Figure 8: Spiral Dart. Even a dart with a complex spiral pattern maintains rotational symmetry.

To test the limits of dart manipulation, a dart with a spiral style line is created. These patterns maintain their rotational symmetry. It is observed that the patterns when flattened, overlap on themselves (see model 19). This means that the spiral patterns could not be created from a single sheet of material. This is an interesting phenomenon.



Model 20: Flat Pattern.

Model 21: 3D pattern.

Model 22: Draw two sets of curved spiral style lines on the pattern.

Model 23: Cut through the two different style lines.

Model 24: Flatten the pattern.

Model 25: Move the pattern apart to show their shape.

Figure 9: Double Spiral Dart. Even a dart with a complex double spiral pattern maintains rotational symmetry.

To fully explore spiral-shaped style lines, a pattern is created that has two spiral style lines running from the apex point to the edge of the garment. The pattern's shape is complex, yet it can be still observed that the spiral patterns have rotational symmetry.

Conclusion

This experiment demonstrates dart manipulation maintains the same geometric shape while changing the style line on the pattern. The style lines that are created have the same rotational symmetry no matter how complex the shape of the dart. This is because the dart legs are cut from the same shape style line when they are a three-dimensional pattern. Rotational symmetry is maintained in all darts, from straight lines to complicated curves and spiral style lines.

Experiment 3: Total Angles in Dart Manipulation

Rationale

This experiment investigates the total sum of the dart angles when a dart is divided into a series of smaller darts. It divides a basic block dart into a series of smaller darts and measures the sum of their dart angles. This experiment also tests darts that have curved style lines.

Hypothesis

The research anticipates that darts should maintain the same total of dart angles when they are divided into smaller darts. This should apply for darts of straight edges and for darts with curved style lines.

Experimental Design

The experiment tests the properties of dart angles when a dart is manipulated into several darts. Through five sets of paper models a basic block dart is divided into multiple darts. The first set is used as a control and moves only one dart to a new location. Two sets test straight-edge darts and the other two test darts with curved style lines. The experiment compares the dart angle of the original block dart with the sum of the total dart angles of the new dart.

Procedure

In this experiment all models start with the same basic dart block dart with a dart angle of 37˚. All patterns are created from a digital file and are printed on 80 gsm paper.

The properties of the style lines are tested in four sets of models:

Set 1: Moving a single dart

Model 1: Leave as the original pattern.

Model 2: Cut a line from the bottom of the pattern to the dart apex point.

Model 3: Cut a line from the side of the pattern to the dart apex point.

Measure and observe the angles of the darts.

Set 2: Two straight edge darts

Model 4: Leave as the original pattern.

Model 5: Draw two straight style lines on the flat pattern.

Model 6: Cut down the two style lines and pivot the pieces so that the original dart is closed. Use tape to join these pieces together.

Measure and observe the angles of the darts.

Set 3: Multiple straight-edge darts

Model 7: Leave as the original flat pattern.

Model 8: Draw six straight style lines on the flat pattern.

Model 9: Cut down the six style lines and pivot the pieces so that the original dart is closed. Use tape to join the original pieces together.

Measure and observe the angles of the darts.

Set 4: Two curved edge darts

Model 10: Leave as the original pattern.

Model 11: Draw two curved style lines on the flat pattern.

Model 12: Cut down the two style lines and pivot the pieces so that the original dart is closed. Use tape to join these pieces together.

Measure and observe the angles of the darts.

Set 5: Multiple curved edge darts

Model 13: Leave as the original flat pattern.

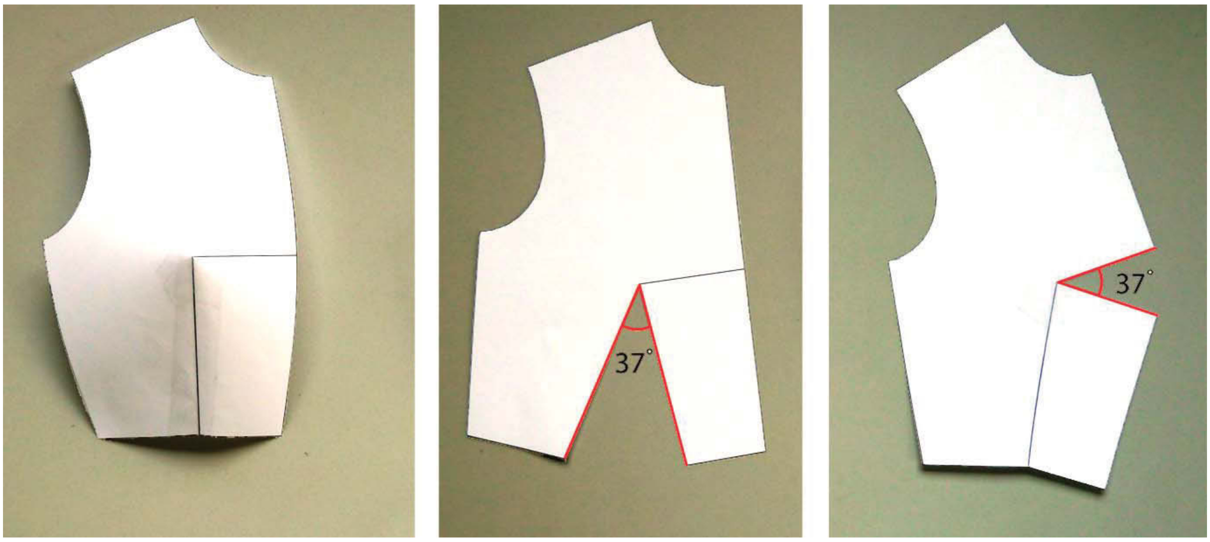
Model 14: Draw six curved style lines on the flat pattern.

Model 15: Cut down the six style lines and pivot the pieces so that the original dart is closed. Use tape to join the original pieces together.

Measure and observe the angles of the darts.

Results

Set 1:



Model 1:	Model 2:	Model 3:
Original 3D pattern.	The pattern with a style line cut from the bottom of the pattern to the apex point.	The pattern with a style line cut from the side of the pattern to the apex point.

Figure 1: When the three-dimensional models are flattened down different lines, they have the same dart angle.

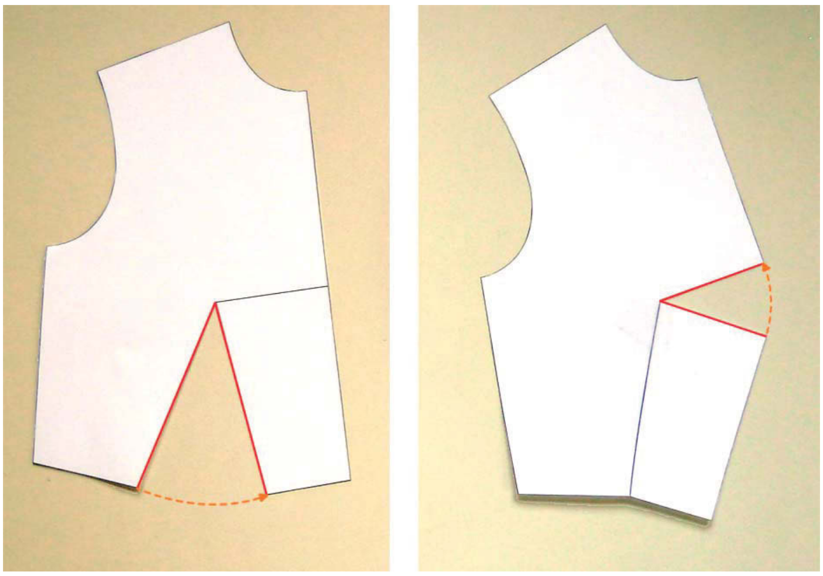


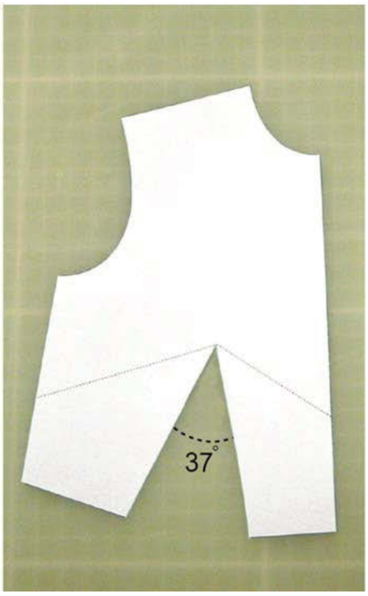
Figure 2: Model 2 compared to model 3. Dart legs in different locations have rotational symmetry.

Both model 2 and model 3 have a dart angle of 37° (see figure 1). The process of moving style lines around a pattern is essentially a process of constructing a pattern that has a dart, then cutting a new style line from the apex point to the edge of a garment.

Set 2:

Model 4:

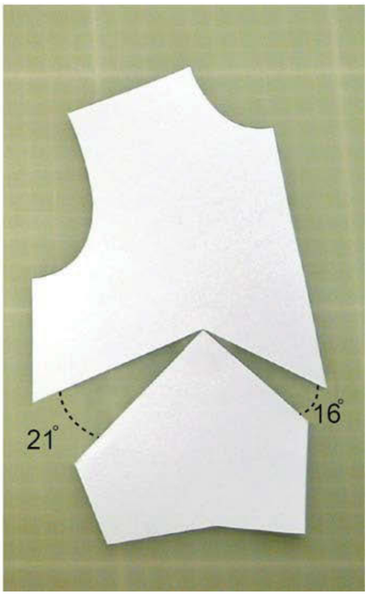
The basic block.



Model 5:

Draw two straight style lines on the pattern.

The dart angle measures 37°.



Model 6:

Pivot the pattern to close the original dart.

The total dart angles measures:

21° + 16° = 37°.

Figure 3: The basic block is divided into two darts. The two new darts still have the same total dart angles as the original dart.

The total angle of the two darts is equal to the dart angle of the original dart.

Set 3:

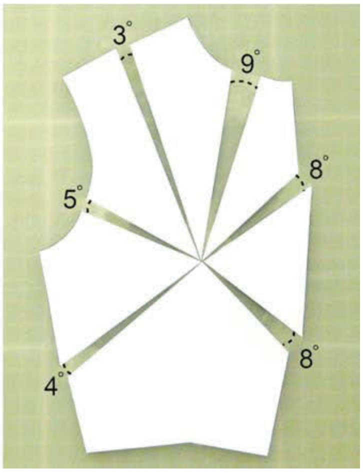
Model 7:

The basic block.

Model 8:

Draw six straight style lines on the pattern.

The dart angle measures 37°.



Model 9:

Pivot the pattern to close the original dart.

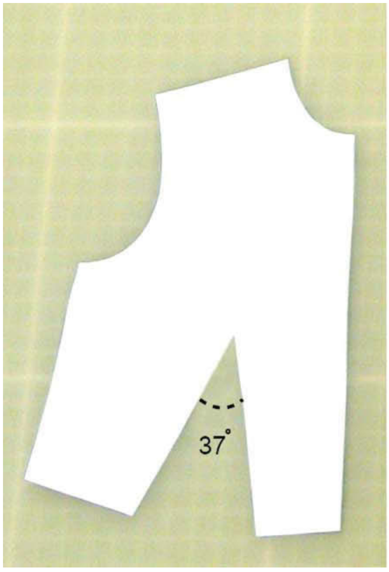
The total dart angles measures:

4° + 5° + 3° + 9° + 8° + 8° = 37°.

Figure 4: The basic block is divided into multiple darts. The darts still have the same total dart angles as the original dart.

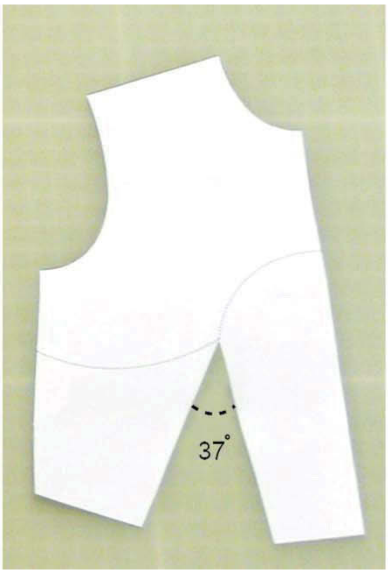
The total angle of the six darts is equal to the dart angle of the original dart.

Set 4:



Model 10:

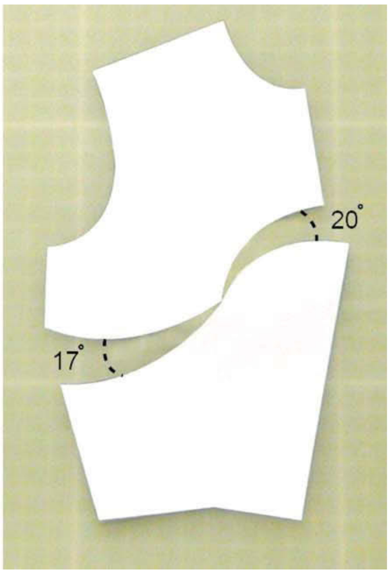
The basic block.



Model 11:

Draw two curved style lines on the pattern.

The dart angle measures 37°.



Model 12:

Pivot the pattern to close the original dart.

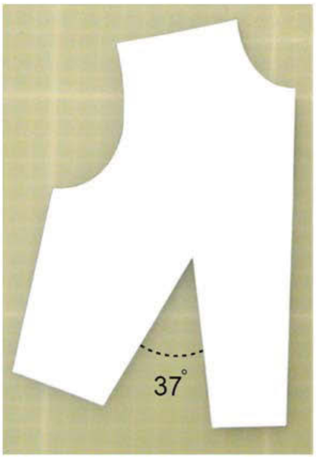
The total dart angles measures:

17° + 20° = 37°.

Figure 5: The basic block is divided into two curved darts. The two new darts still have the same total dart angles as the original dart.

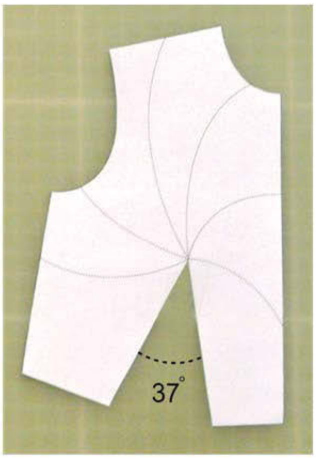
The total angle of the two curved darts is equal to the dart angle of the original dart.

Set 5:



Model 13:

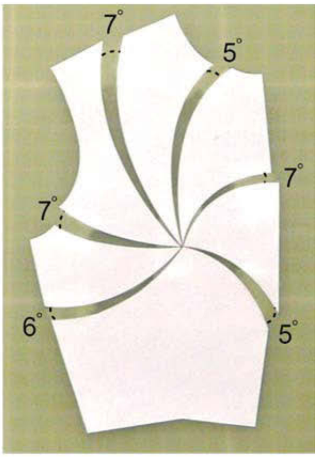
The basic block.



Model 14:

Draw six curved style lines on the pattern.

The dart angle measures 37°.



Model 15:

Pivot the pattern to close the original dart.

The total dart angles measures:

6° + 7° + 7° + 5° + 7° + 5° = 37°.

Figure 6: The basic block is divided into multiple curved darts. The darts still have the same total dart angles as the original dart.

The total angle of the six curved darts is equal to the dart angle of the original dart.

Conclusion

These experiments demonstrate that if a dart is divided into multiple darts, that the sum of the total dart angles will be equal to the original dart angles. This applies to darts with straight or curved style lines.

Experiment 4: Dissecting Cones

Rationale

This experiment observes the geometric properties of cones as they are dissected into smaller parts. Darts essentially make flat patterns cone-shaped. Observing the properties of cones makes it possible to understand the properties of darts. In conics a “frustum” is a cone with its top cut off. This experiment explores the properties of frustums in relation to patternmaking.

Hypothesis

The research anticipates that cutting up cones will create smaller cones and frustums. The smaller cones should have similar geometric properties to the cones they were cut from. The frustums should also have properties similar to the cones they were cut from.

Experimental Design

The experiment is designed to take paper models of cones and dissect them horizontally into smaller pieces. The experiment is divided into four sets of models. The first set cuts a cone in half. The second set cuts a cone into three pieces. The third set compares the three-dimensional and flat patterns of a cone which have been cut into three parts. The fourth set takes a basic block pattern and cuts the top off the pattern. In sum, experiments examine the geometric properties of the cones and frustums.

Procedure

All paper models are printed from digital files on 80 gsm paper, and are assembled into three-dimensional models using tape. The properties of cones are tested in four sets of models:

Set 1: Cutting a cone in half

Construct three paper models of a cone with a dart angle of 40°. Draw an additional circle in the middle of the cone which is centred on the apex point of the cone.

Model 1: Leave as the original pattern.

Model 2: Cut the top off the cone by cutting along the circular line in the middle of the cone.

Model 3: Cut the top off the cone. Take the bottom part of the cone (the frustum) and cut down the dart line. Then flatten the pattern.

Observe the three-dimensional and flat patterns created by these models.

Set 2: Cutting a cone in three sections

Construct three paper models of a cone. The first two paper models are of a cone with a dart angle of 20°. The third model has the same cone pattern with two additional circles drawn on the pattern which are centred at the cone's apex point. This divides the pattern into three separate parts.

Model 4: Leave as the original flat pattern.

Model 5: Construct the original pattern in three-dimensions.

Model 6: Cut the cone into three different pieces by cutting horizontal cross sections of the cone. These are created by drawing a circle on the flat pattern which is centred on the dart apex.

Observe the three-dimensional and flat patterns created by these models.

Set 3: Comparing the flat and three-dimensional patterns of frustums

Construct four paper models of a cone with a dart angle of 20° with a radius of 6.3 cm. Draw two circles centred on the cone apex on all of the patterns with radii of 2.5 cm and 4.6 cm. These circular lines divide the pattern into three separate parts.

Model 7: Leave as the original 3D pattern.

Model 8: Cut down the dart line and flatten the pattern.

Model 9: Cut the cone into three separate sections.

Model 10: Cut the cone into three separate sections. Then cut down the dart line to flatten each of the patterns.

Observe the three-dimensional and flat patterns created by these models.

Set 4: Cutting the top off a basic block

Construct two paper models of a basic block dart. On the second model, draw an additional circle on the flat pattern centred on the dart apex. Then cut through this circular line in order to neatly cut a cone off the pattern.

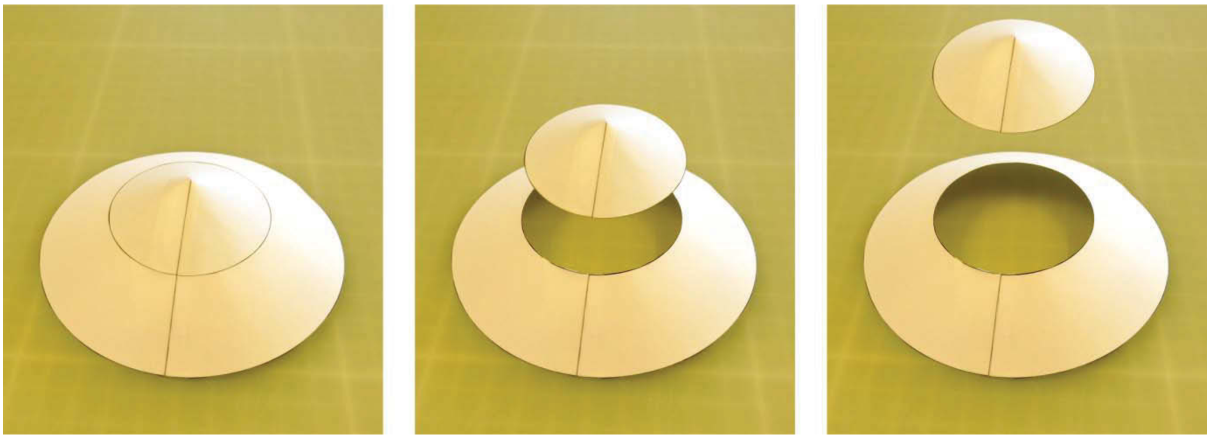
Model 11: Leave as the original pattern.

Model 12: Cut the top off the cone. This is achieved by cutting around a circle that is centred on the middle of the cone.

Observe the three-dimensional and flat patterns created by these models.

Results

Set 1: Cutting a cone in half

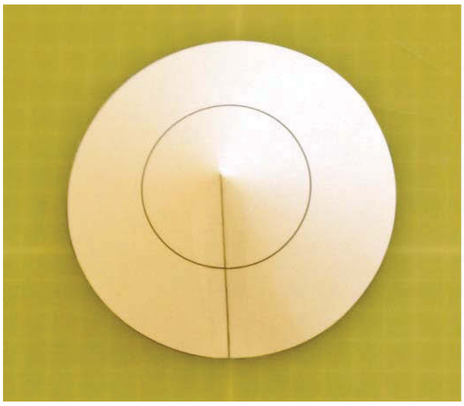


Model 1: The cone.

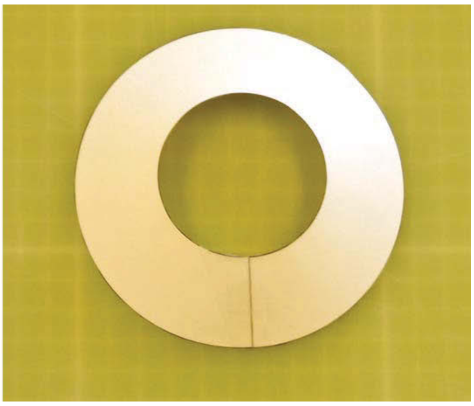
Model 2: The top cut off the cone.

Model 3: The cone in two pieces.

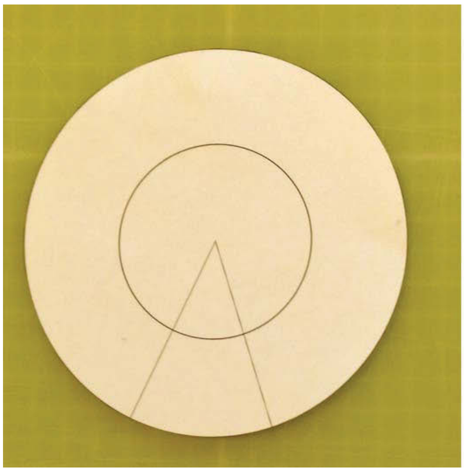
Figure 1: A cone cut in half to create a smaller cone and a frustum.



The cone in 3D.

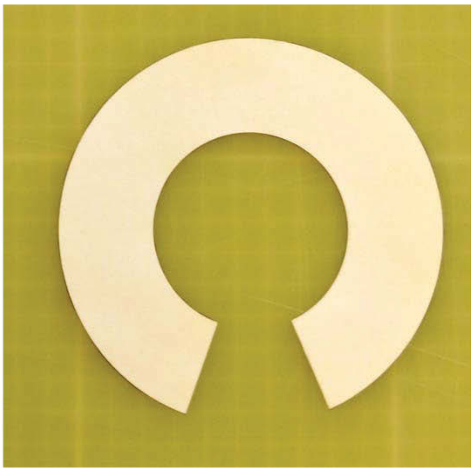


The frustum in 3D.



Model 1:

The cone as a flat pattern.

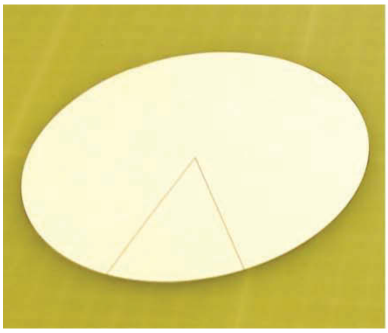


Model 3:

The frustum as a flat pattern.

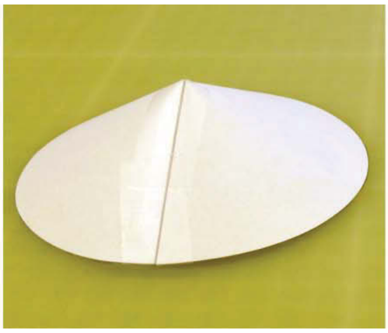
Figure 2: A frustum has the geometric properties of a cone.

Set 2: Cutting a cone in three sections



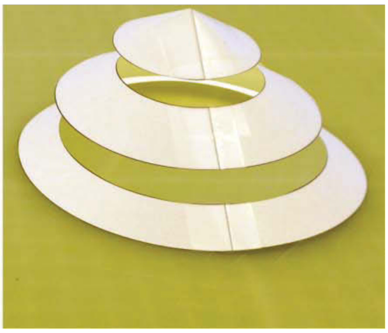
Model 4:

A flattened cone.



Model 5:

A cone in 3D.



Model 6:

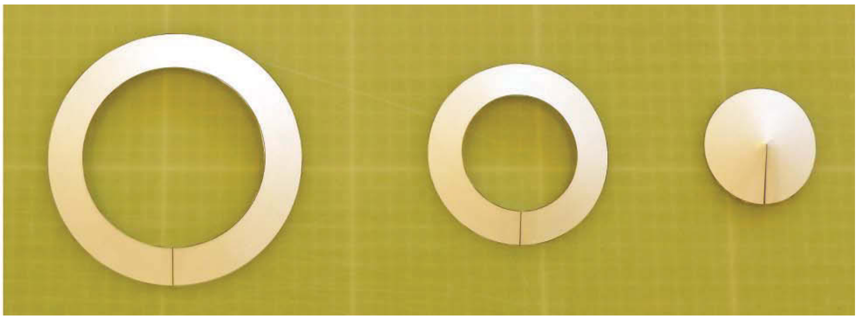
A cone cut into pieces.

Figure 3: A cone can be deconstructed into frustums.

Set 3: Comparing the flat and three-dimensional patterns of frustums

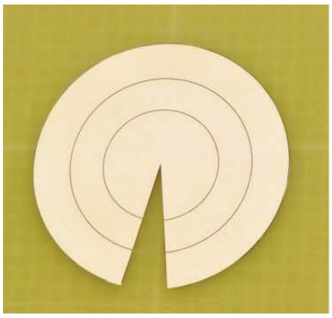
Model 7:

A cone as a flat pattern.



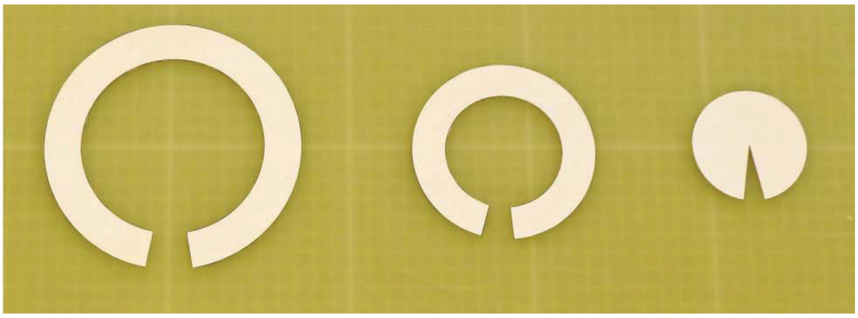
Model 9:

A cone cut up into pieces as a flat pattern.



Model 8:

A cone as a 3D pattern.



Model 10:

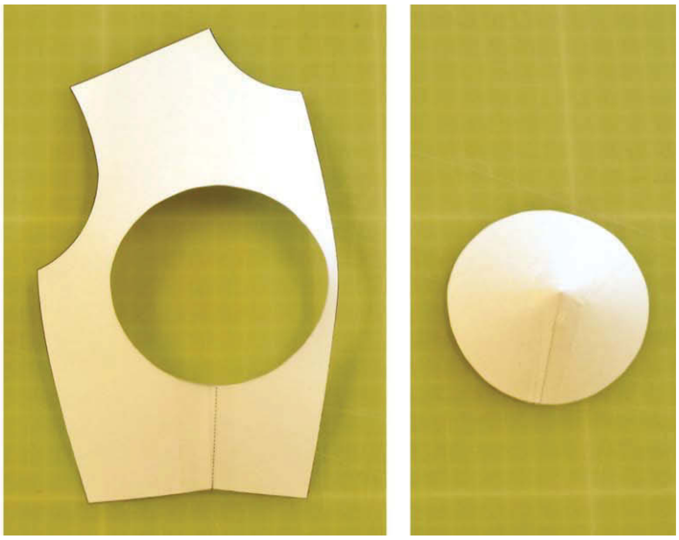
A cone cut up into pieces as a 3D pattern.

Figure 4: A cone dissected into a series of cones and frustums.

Set 4: Cutting a cone of the top of a basic block

Model 11:

A basic block pattern in 3D.



Model 12:

A basic block pattern in 3D in which a cone is cut off the top of the pattern.

Figure 5: A pattern piece still has the geometric properties of a cone and a frustum.

Observations

Set 1: Cutting a cone in half.

Cutting a cone in half creates one smaller cone and one frustum. The frustum has the properties of the cone with its dart apex in the same location as the original cone. A frustum is essentially a cone with its tip cut off.

Set 2: Cutting a cone in three sections.

When a cone is cut into multiple pieces, the tip of the cone becomes a smaller cone and the rest become frustums.

Set 3: Cutting a cone in three sections.

The different frustum patterns have properties similar to the original cone. A frustum has a dart that is centred at the apex. The only difference is, the tip of the cone is cut off (see model 8).

Set 4: Cutting a cone of the top of a basic block.

The tip of a basic block is a cone. When the tip of a basic block is cut off, the rest of the pattern is a frustum with curved edges. This pattern has the geometric properties of the original cone.

Conclusion

This experiment demonstrates that cones that are cut apart have the properties of cones. The cone tip and the frustum have the geometric properties of the cone they are originally cut from. Patterns with darts have the same properties as a cone, even though the edges of the pattern may have a shape different from a cone.

2. Gussets

Experiment 5: **Gusset manipulation**

Experiment 6: **Total angles in gusset manipulation**

Experiment 7: **The shape of gussets after gusset manipulation**

Experiment 8: **A comparison of the properties of darts and gussets**

Aim

This group of experiments investigates the properties of gussets, the pieces of fabric sewn into a garment to add fullness. While patternmakers will often add fullness to a pattern to modify its shape, they do not have a "manipulation" technique akin to dart manipulation. The experiments thereby explore "gusset manipulation", a technique that maintains the garment's three-dimensional form while moving the seam lines or "style lines" around it. It considers the properties of gusset apex points, gusset angles, gusset manipulation and the dissection of a gusset into pieces. It also compares the properties of darts to those of gussets to show similarities and differences.

Method

The first experiment explores the properties of "gusset manipulation" and how style lines can be moved around the garment while maintaining the geometric form. The second experiment considers the total gusset angles of a pattern when a gusset is divided into a smaller series. The third investigates how moving the gusset to different locations can create gussets of different shapes. The fourth compares the properties of darts and gussets, whereby different gusset properties are explored, including: changing the cone angle, radius, apex location and dissecting the cones into smaller pieces.

Analysis

These experiments show that the techniques of manipulating a pattern with gussets are as important as using darts. Darts create surfaces with spherical geometry while gussets make surfaces hyperbolic in shape. "Gusset manipulation" is a useful way of manipulating its location while maintaining the garment's original form. Although gussets and darts have similar properties in that they both maintain the total amount of cone angles, gussets have unique properties. A dart can be moved to any location and remain the same, but a gusset will change shape depending on the location of the style line. When darts and gussets are dissected into smaller pieces, each part maintains the geometric properties of the original shape.

Experiment 5: Gusset Manipulation

Rationale

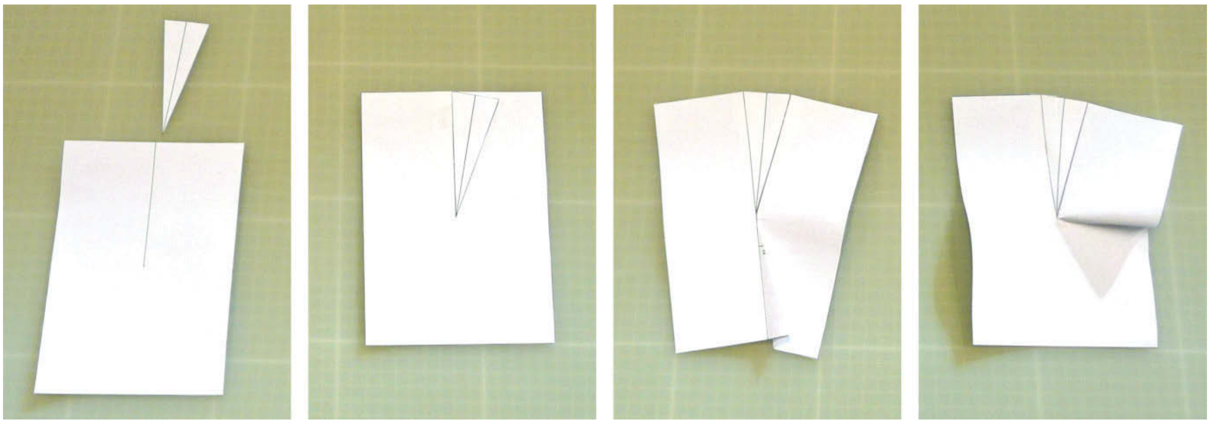
Manipulating patterns that have fullness is a phenomenon not as well documented as dart manipulation. Adding fullness to a pattern is often seen as a way of altering it. There are few attempts to manipulate patterns that have fullness with the same level of precision as dart manipulation. This experiment manipulates patterns where an apex is more than 360˚. This means the patterns cannot be made from a single flat sheet of material. A gusset is the addition of a wedge-shaped piece of material sewn into a pattern. These experiments will explore "gusset manipulation" and the geometric properties of gussets as they are moved around a pattern.

Hypothesis

The research anticipates that if dart manipulation moves style lines around apex points with less than 360˚, then gusset manipulation is a similar process to manipulating patterns with apex points of more than 360˚.

Experimental Design

The experiment tests the properties of gusset manipulation. A basic gusset is created by inserting a straight-edged gusset into a flat pattern (see figure 1). This creates a pattern with an apex of more than 360˚. A style line is then drawn on the pattern in a different location. A new gusset is then cut out of the pattern in a new location. The experiment places gussets in different locations and observes their shape.



A gusset is inserted into a flat pattern.

The gusset creates a pattern with more than 360°.

The gusset is shown with fullness folded out to flatten the pattern.

The gusset in 3D.

Figure 1: The basic gusset: a gusset inserted into a flat pattern.

Procedure

Through three sets of experiments gussets are manipulated and cut out of a pattern at different locations.

Start each experiment with a basic gusset dart. This is a rectangular pattern with a wedge-shaped gusset of 21° inserted into the top of the garment. All patterns are created from a digital file and are printed on 80 gsm paper.

Set 1:

Model 1: Start with a basic gusset pattern. Draw a new gusset on the bottom right edge of the garment. The total angles of this gusset should be 21°.

Model 2: Cut down the first line of the new gusset of the new pattern.

Model 3: Cut down the second line of the gusset. Remove the new gusset from the flattened pattern.

Set 2:

Model 4: Start with a basic gusset pattern. Draw a new gusset on the bottom of the garment. One line should be vertical while the other line points to the bottom right side of the pattern. The total angles of this gusset should be 21°.

Model 5: Manipulate the pattern to pinch out the gusset, fold it over and flatten the pattern.

Model 6: Cut down both lines of the pattern and remove the new gusset from the flattened pattern.

Set 3:

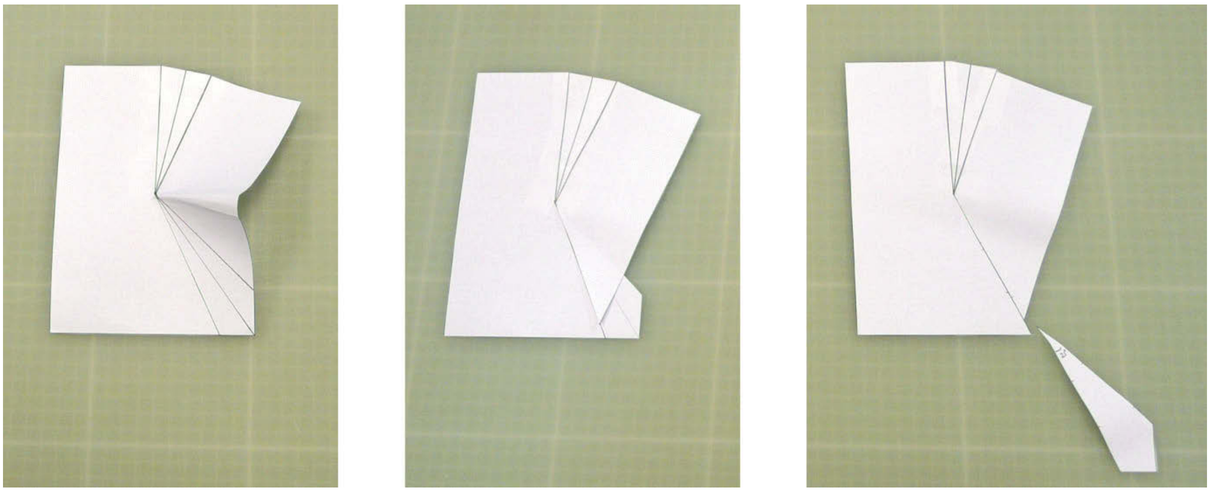
Model 7: Start with a basic gusset pattern. Draw a new gusset on the bottom of the garment. Draw a gusset which mirrors the size and shape of the original gusset on the bottom of the pattern. The total angles of this gusset should be 21°.

Model 8: Manipulate the pattern to pinch out the gusset, fold it over and flatten the pattern.

Model 9: Cut down both lines of the pattern and remove the new gusset from the flattened pattern.

<u>**Results**</u>

Set 1:



Model 1:
A gusset is drawn in a new location.

Model 2:
Cut down the edge of the new gusset and flatten the pattern.

Model 3:
Cut down the edge of where the pattern overlaps itself and a new gusset is created.

Figure 2: Sequence of gusset manipulation.

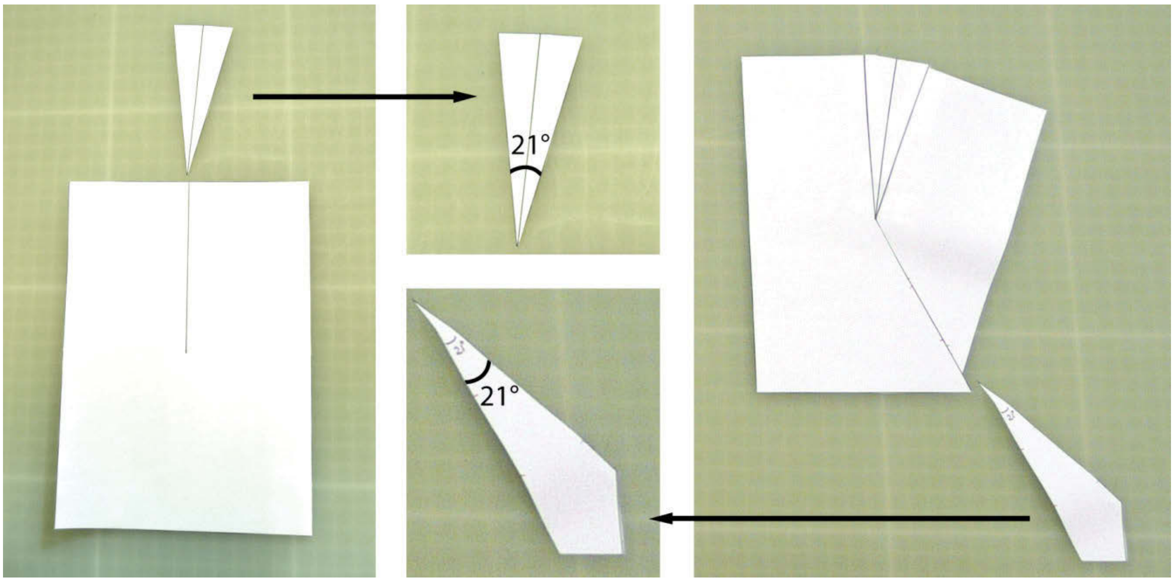


Figure 3: The angles of the basic gusset have the same total of angles as the new gusset.

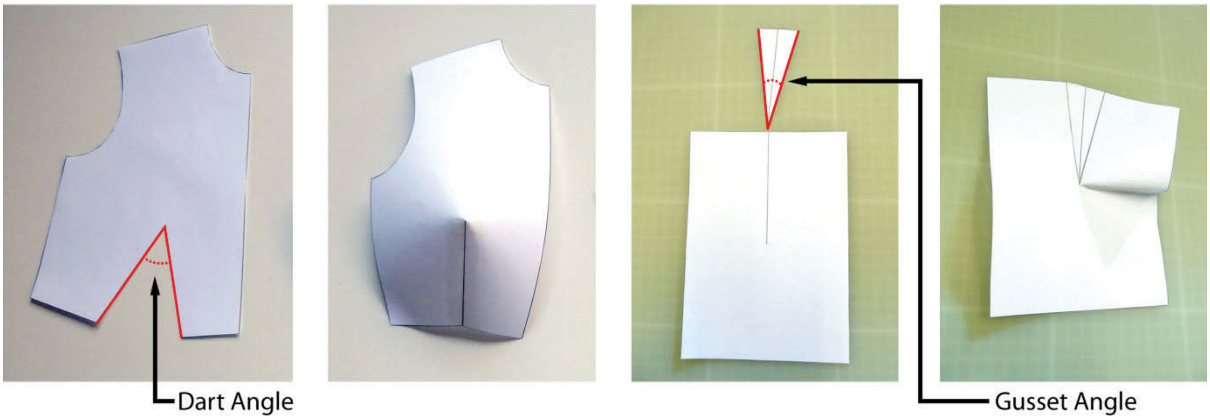
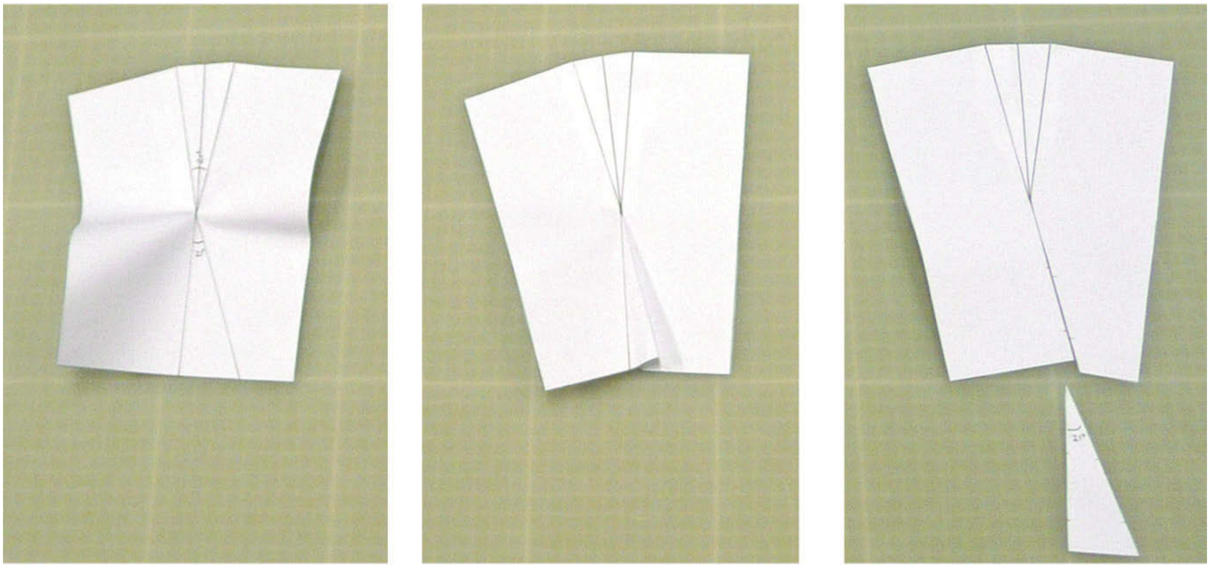


Figure 4: If darts have dart angles, then gussets should have gusset angles.

The original gusset is a triangular shape while the new gusset is a diamond shape (see figure 3). Dart and gusset manipulation have similar properties. The main difference is that darts constitute the absence of material while gussets are the addition of material (see figure 4). Dart angles are always the same because they are the absence of material, while gussets require the addition of material which can be different depending on the location of the gusset.

Set 2:



Model 4:
A gusset is drawn in a new location.

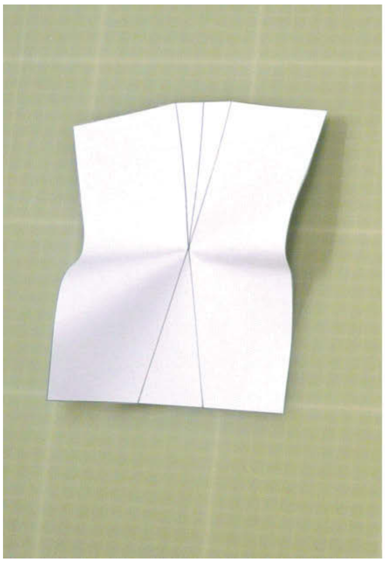
Model 5:
The pattern can be folded to show the location of the new gusset.

Model 6:
The new gusset is cut out of the pattern.

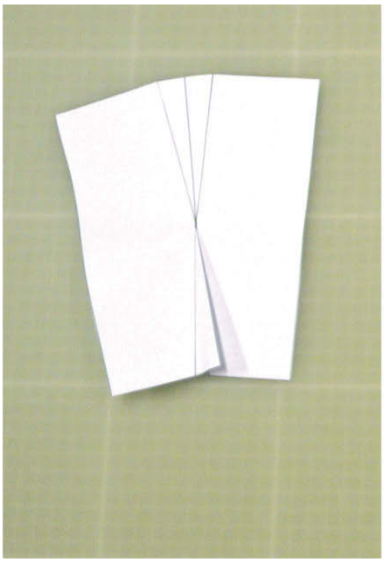
Figure 5: Gusset manipulation in a different location.

In this experiment the new gusset is a different shape to the original gusset. The original gusset is an equilateral triangle, while the new gusset is a right-angle triangle.

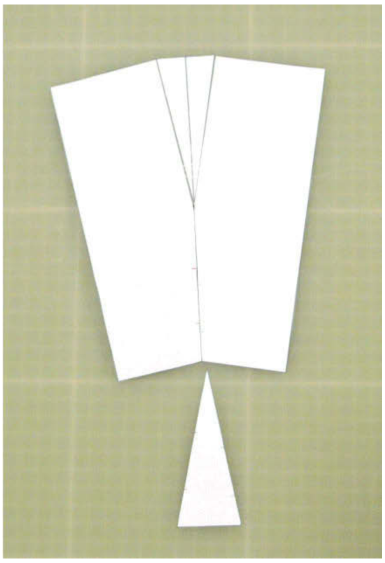
Set 3:



Model 7:
A gusset is drawn in a new location.



Model 8:
The pattern can be folded to show the location of the new gusset.



Model 9:
The new gusset is cut out of the pattern.

Figure 6: Gussets of different locations create different shapes.

In this experiment the new gusset is the exact shape of the original gusset.

Conclusion

This experiment shows that gusset manipulation has similar yet slightly different properties to dart manipulation. In gusset manipulation, placing gussets in different locations creates gussets of different shapes. Gussets have different properties to darts as they are additional material added to a pattern, rather than material removed from a pattern.

Experiment 6: Total Angles in Gusset Manipulation

Rationale

This experiment investigates the total sum of the gusset angles when a gusset is divided into a series of smaller gussets. It will divide a basic gusset pattern into a series of smaller gussets and measure the sum of their gusset angles. The experiment will also test gussets with curved style lines.

Hypothesis

The research anticipates that gusset patterns should maintain the same total of gusset angles when divided into smaller gussets. This should apply to both gussets with straight edges and gussets with curved style lines.

Experimental Design

The experiment investigates the properties of gusset angles when a dart is manipulated into several gussets. It is tested through five sets of paper models. All the iterations start with the same gusset patterns and divide that pattern into multiple gussets. The first set cuts two smaller gussets out of a basic gusset. The second test cuts multiple gussets out of a pattern. Here, six gussets are cut out. The third set cuts a single curved gusset from a pattern, the fourth cuts out two curved gussets, and the fifth set cuts out six curved gussets. These iterations will compare the gusset angle of the original pattern with the sum of the total gusset angles of the new pattern.

Procedure

Through five sets of iterations, it manipulates multiple gussets and cuts out the pattern in different locations.

All models start with the same gusset block pattern. This is a rectangular pattern with a wedge shape gusset of 21° inserted into the top of the garment. All patterns are created from a digital file and are printed on 80 gsm paper (see figure 1).

The properties of the style lines are tested in five sets of models:

Set 1:

Model 1: Start with the basic gusset pattern. Draw two new gusset locations on the pattern.

Model 2: The size of the gusset can be determined by pinching out the gussets so that the pattern lies flat.

Model 3: Cut the new gussets out of the pattern and flatten the pattern.

Measure the total dart angles of the new gussets.

Set 2:

Model 4: Start with the basic gusset pattern. Draw six new gusset locations on the pattern.

Model 5: The size of the gusset can be determined by pinching out the gussets so that the pattern lies flat.

Model 6: Cut the new gussets out of the pattern and flatten the pattern.

Measure the total dart angles of the new gussets.

Set 3:

Model 7: Start with the basic gusset pattern. The basic gusset has an angle of 21°.

Model 8: Draw in a new curved gusset on the rectangular pattern. The new gusset should have a gusset angle of 21°. The curved gusset should have rotational symmetry.

Model 9: Cut down the rectangular pattern from the edge to the apex point. Insert the dart into the rectangular pattern and use tape to attach the garment.

Model 10: Cut through the curved edge of the new dart.

Model 11: Flatten the pattern.

Model 12: Cut through the second edge of the curved gusset and remove the new curved shape gusset from the pattern.

Measure the total dart angles of the new gussets.

Set 4:

Model 13: Start with the basic gusset pattern. Draw two new curved gussets on the rectangular pattern. Each of the patterns had a dart angle of 10.5°. The curved gusset should have rotational symmetry. Then insert the triangular-shaped wedge into the rectangular pattern.

Model 14: The size of the gusset can be determined by pinching out the gussets so that the pattern lies flat.

Model 15: Cut down the edges of the curved darts.

Model 16: Cut down the curved edge of the new dart patterns and flatten the pattern. Remove the two new curved dart patterns from the pattern.

Measure the total dart angles of the new gussets.

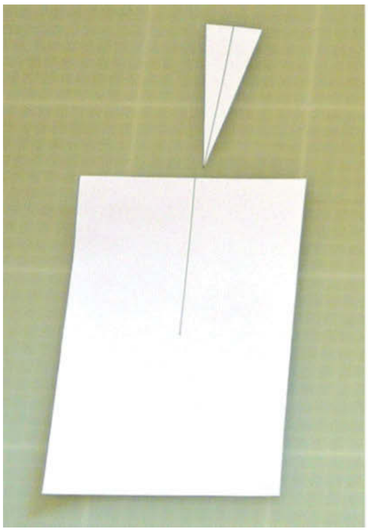
Set 5:

Model 17: Start with the basic gusset pattern. Draw four new curved gussets on the rectangular pattern. The curved gussets have gusset angles of: 5°, 6°, 5° and 5°. The curved gusset should have rotational symmetry.

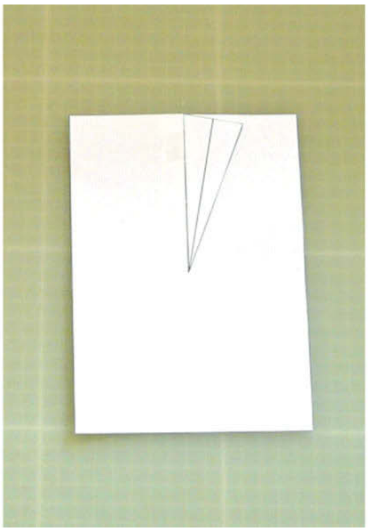
Model 18: Next, insert the triangular-shaped wedge into the rectangular pattern.

Model 19: Cut down one of the edges of each of the curved gusset patterns and flatten the pattern.

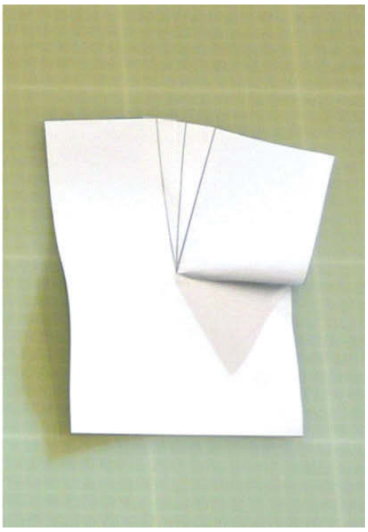
Model 20: Cut down both edges of the curved gussets and remove the new curved gussets from the flat pattern.



A gusset of 21° is
Inserted into a flat pattern.



The gusset creates a
pattern more than 360°.

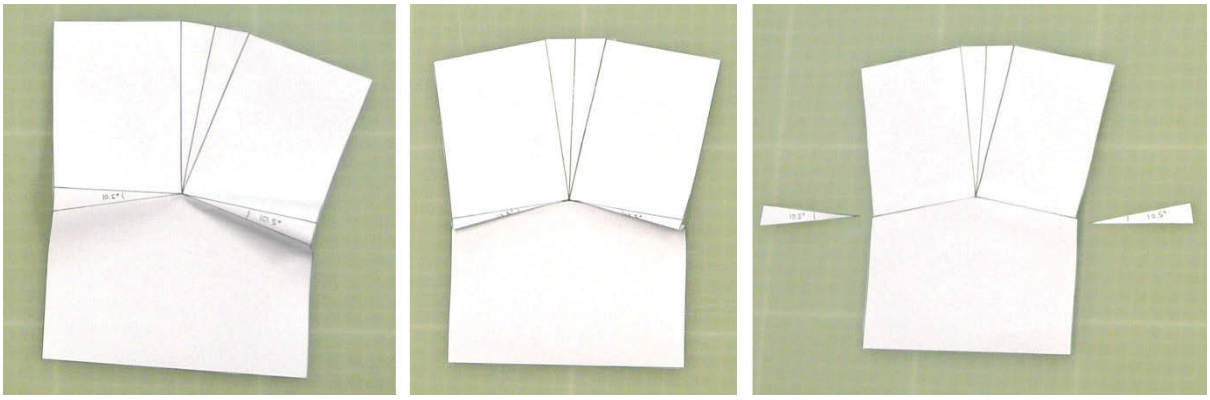


A gusset of 21° is
Inserted into a flat pattern.

Figure 1: The basic gusset. A gusset inserted into a flat pattern.

Results

Set 1:



Model 1:
The position of two new gussets
is marked on the pattern.

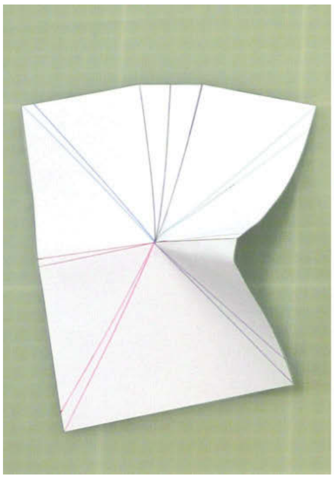
Model 2:
Two gussets are folded out of
the pattern so that the pattern lies flat.

Model 3:
Two gussets are cut out.

Figure 2: Two gussets.

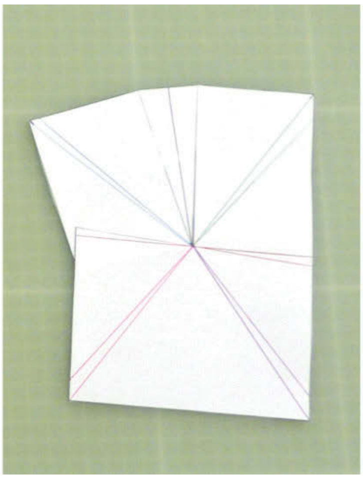
The new pattern with multiple gussets maintains the same amount of gusset angles as the original pattern. It is noted that the size and shape of the gusset changes depending on the location of the new gussets. The final pattern with two new gussets also has a different shape to the original pattern. The original pattern has a rectangle and a triangular wedge, while the new pattern has two smaller triangular wedges and an octagonal pattern.

Set 2:



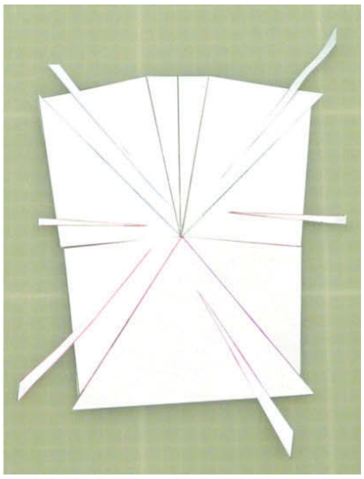
Model 4:

The position of six new gussets is marked on the pattern.



Model 5:

Cut out the gussets and flatten the pattern.

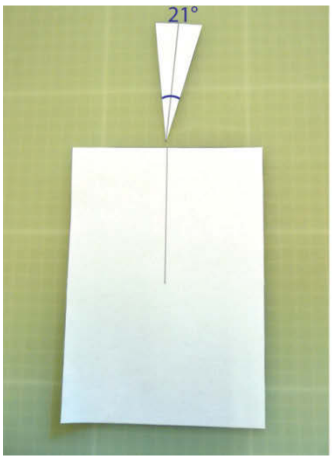


Model 6:

Six gussets are cut out of the pattern.

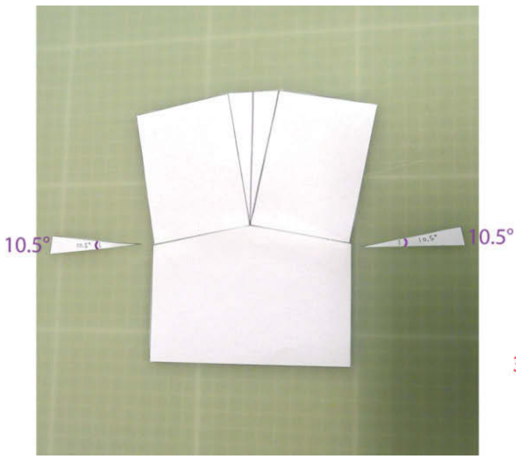
Figure 3: Multiple gussets. The sum of the gusset angles, starting clockwise from the top of gusset: 4° + 4° + 3° + 3° + 4° + 3°= 21°

The new gussets have the same total amount of gusset angles as the original pattern. It is observed that in this experiment and in the previous set, the sum of the gusset angles remains the same no matter the amount or location of the darts (see figure 4). The final pattern also has a very different shape to the basic gusset pattern. It has six gussets of different shapes. The flattened pattern resembles a series of triangular wedges joined together. This creates a complex twelve-sided shape.



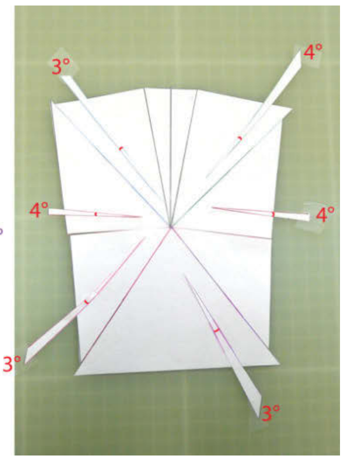
Basic gusset:

Total gusset angles: 21°



Model 3:

Total gusset angles: 10.5° + 10.5° = 21°



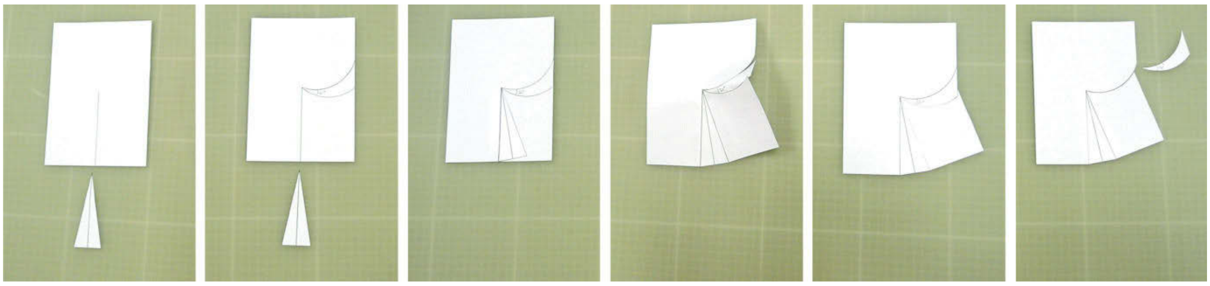
Model 6:

Total gusset angles :

4° + 4° + 3° + 3° + 4° + 3° = 21°

Figure 4: Gussets have the same total gusset angles.

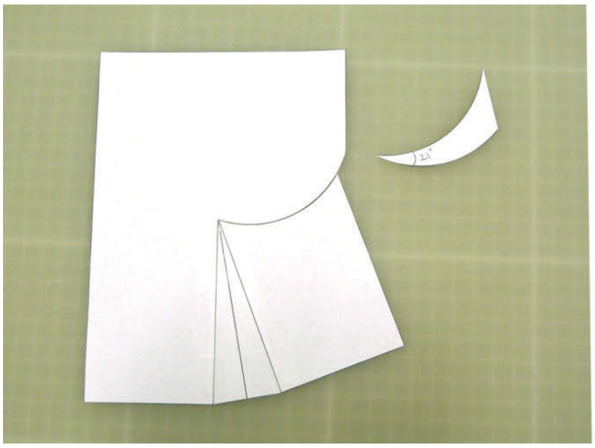
Set 3:



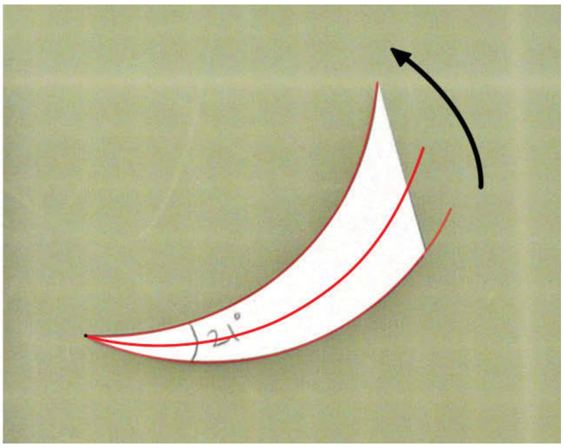
Model 7: Flat pattern and gusset.	Model 8: The new gusset drawn on the pattern.	Model 9: Attach the gusset to the main pattern.	Model 10: Partially cut down the new gusset.	Model 11: Cut down the leg of the gusset.	Model 12: The new gusset cut out from the pattern.

Figure 5: A curved gusset.

The new curved gusset has the same amount of gusset angles as the original pattern. It is observed that the curved gusset has rotational symmetry (see figure 6).



A curved gusset can be cut out of the gusset.

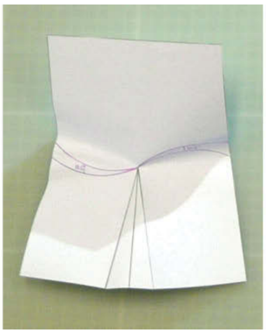


This gusset has rotational symmetry.

Figure 6: Using gusset manipulation: a curved gusset can be cut out of a pattern with a gusset.

Set 4:

Model 13:
Draw two new curved gussets.



Model 14:
Insert the gusset into the pattern.

Model 15:
Cut down the top edge of each of the curved gussets and flatten the pattern.

Model 16:
Cut down the bottom edge of the curved gussets and flatten the pattern.

Figure 7: Two curved gussets. The sum of gusset angles is 10.5˚ + 10.5˚ = 21˚

The new curved gusset with multiple gussets has the same amount of gusset angles as the original pattern.

Set 5:

Model 17:
Draw four new curved gussets.

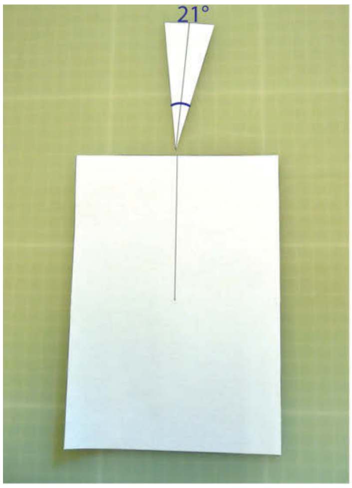
Model 18:
Insert the gusset into the pattern.

Model 19:
Cut down the top edge of each of the curved gussets and flatten the pattern.

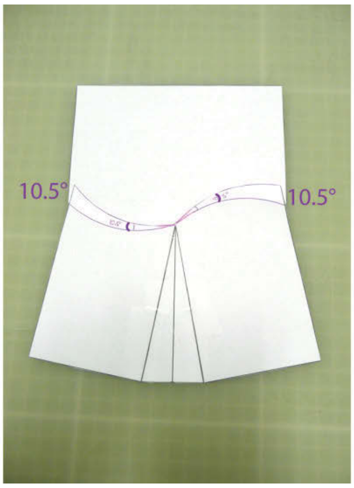
Model 20:
Cut down the bottom edge of each of the curved gussets and flatten the pattern.

Figure 8: Multiple Gussets: The total gusset angles clockwise starting from the left, are: 5˚ + 6˚ + 5˚ + 5˚ = 21˚

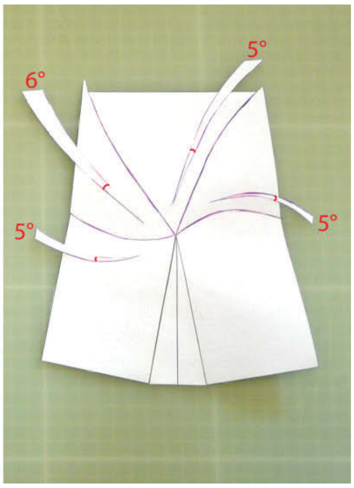
The new curved gusset with multiple gussets has the same amount of gusset angles as the original pattern. The final flat pattern also makes a curved shape which is very different from the final pattern.



Total gusset angles: 21˚



Total gusset angles: 10.5˚ + 10.5˚ = 21˚



Total gusset angles: 5˚ + 6˚ + 5˚ + 5˚= 21˚

Figure 9: Curved gussets have the same total gusset angles.

Conclusion

In this experiment it is evident that when multiple gussets are cut out of a pattern they have the same total of gusset angles as the original pattern. The sum of the new gussets always equals the amount of the initial gusset angles. This applies to both gussets with straight edges and curved gussets.

Experiment 7: The Shape of Gussets after Gusset Manipulation

Rationale

This experiment explores the relationship between the location of a new gusset and its shape when using the technique of gusset manipulation. In gusset manipulation, moving a gusset to a new location often changes the size and shape of the gusset pattern. This is examined by moving the gussets to different locations on the same pattern. It also investigates how the length of the gusset location affects the size of the shape of the final gusset. Gussets with shorter radii are compared to gussets with longer radii. These iterations explore the relationship between the length of a gusset location and gusset shape.

Hypothesis

The research anticipates that gussets in different locations create gussets of different lengths. It is possible that gussets in different locations can create gussets of different shapes and sizes.

Experimental Design

The experiment tests the properties of gusset manipulation through several iterations. The first part starts with a gusset pattern made of a square pattern with a triangular gusset inserted. Using gusset manipulation, new gussets are cut from this pattern in many diverse locations. It then compares the size and shape of the new gussets.

The second part of the experiment compares the relationship between the radius length of the gusset location and the size and shape of the final gusset. This time the gusset is inserted into a circular pattern. This ensures that different gussets cut in different locations will all have the same radius length. The research tests the relationship between radius of the gusset and the final shape of the gusset.

The third part compares the properties of gussets with different lengths. In one iteration a series of straight lines are drawn out from the centre of a square pattern to observe the many possible gusset lengths. It then takes a gusset pattern with the longest gusset length and compare it to a gusset with the shortest radius length. This iteration compares gusset patterns of different sizes and compares their properties.

Procedure

The properties of gussets are tested in three parts:

<u>Part 1</u>: Gusset manipulation on a square pattern

This experiment starts with the same gusset pattern (see figure 1). Using gusset manipulation, gussets are cut out of different locations on the pattern.

Set 1: Gusset manipulation on the top of pattern

Model 1: Create a pattern consisting of a triangular gusset with an angle of 43° inserted into a square pattern with a length of 12.3 cm. Draw a circle on the pattern to show the radius of the new gusset location. Draw a new gusset of 43° on the top of the pattern.

Model 2: Cut down the line from the bottom of the pattern to the central apex and insert the gusset into pattern using tape.

Model 3: Cut the new gusset out from the top of the pattern. Flatten the pattern and observe the properties of the new gusset.

Set 2: Gusset manipulation on the top left corner of pattern

Model 4: Start with the same pattern as the last experiment, only this time draw the new gusset location in the top left corner of the square.

Model 5: Cut down the line from the bottom of the pattern to the central apex and insert the gusset into pattern using tape.

Model 6: Cut the new gusset out from the top left corner of the pattern. Flatten the pattern and observe the properties of the new gusset.

Set 3: Gusset manipulation on the top left of pattern

Model 7: Start with the same pattern as the last experiment. This time draw the new gusset location in the top left of the square.

Model 8: Cut down the line from the bottom of the pattern to the central apex and insert the gusset into pattern using tape.

Model 9: Cut the new gusset out from the top left side of the pattern. Flatten the pattern and observe the properties of the new gusset.

Set 4: Gusset manipulation on the left of pattern

Model 10: Start with the same pattern as the last experiment. This time draw the new gusset location on the left of the square.

Model 11: Cut down the line from the bottom of the pattern to the central apex and insert the gusset into pattern using tape.

Model 12: Cut the new gusset out from the left side of the pattern. Flatten the pattern and observe the properties of the new gusset.

Part 2: Gusset manipulation on a circular pattern

This experiment starts with the same gusset pattern (see figure 2) and cuts out new gussets in different locations using gusset manipulation.

Set 5: Gusset manipulation on the left of pattern

Model 13: Create a pattern which consists of a triangular gusset with an angle of 43° inserted into a circle pattern with a radius length of 6 cm. Draw a new gusset of 43° on the left side of the pattern.

Model 14: Cut down the line from the bottom of the pattern to the central apex and insert the gusset into the pattern using tape.

Model 15: Cut the new gusset out from the left side of the pattern. Flatten the pattern and observe the properties of the new gusset.

Set 6: Gusset manipulation on the right of pattern

Model 16: Create a pattern identical to the last experiment and this time draw a new gusset of 43° on the right side of the pattern.

Model 17: Cut down the line from the bottom of the pattern to the central apex and insert the gusset into the pattern using tape.

Model 18: Cut the new gusset out from the right of the pattern. Flatten the pattern and observe the properties of the new gusset.

Set 7: Gusset manipulation on the top of pattern

Model 19: Create a pattern identical to the last experiment and this time draw a new gusset of 43° on the top of the pattern.

Model 20: Cut down the line from the bottom of the pattern to the central apex and insert the gusset into the pattern using tape.

Model 21: Cut the new gusset out from the top of the pattern. Flatten the pattern and observe the properties of the new gusset.

<u>Part 3</u>: Gussets with different lengths

This experiment compares how the location of a gusset affects the size of the gusset. Starting with a square pattern, a gusset is inserted into the pattern at different locations. The apex of the pattern is at the centre of the square and gussets in different locations will have radii of different lengths. These gussets will have the same gusset angle but a different radius length. This iteration compares a pattern with the shortest gusset radius with a pattern with the longest dart radii.

Set 8: Gussets of different radii

Model 22: Create a pattern which is a square of 12. 3 cm. Draw a circle on the pattern to show the different radius lengths on the pattern. Draw lines in different colours from the centre of the pattern to the edge of the pattern to show the location of possible gussets.

Observe the relationships between the different lengths of the material.

Set 9:

Model 23: Create a pattern which is a square of 12.3 cm. Draw a circle on the pattern to show the different radius lengths on the pattern. Draw a line from the central apex to the top right corner of the pattern. This will create a pattern with the longest radius length. Create triangular-shaped gusset of angle 43° which can be inserted into the square pattern. Draw the location of a new gusset on the bottom of the square pattern by drawing a triangle of 43°.

Model 24: Cut down the line on the top right corner of the pattern to the central apex and insert the gusset into the pattern using tape.

Model 25: Cut the new gusset out from the bottom of the pattern. Flatten the pattern and observe the properties of the new gusset.

Compare this pattern to the gusset pattern in set 1 and compare their properties.

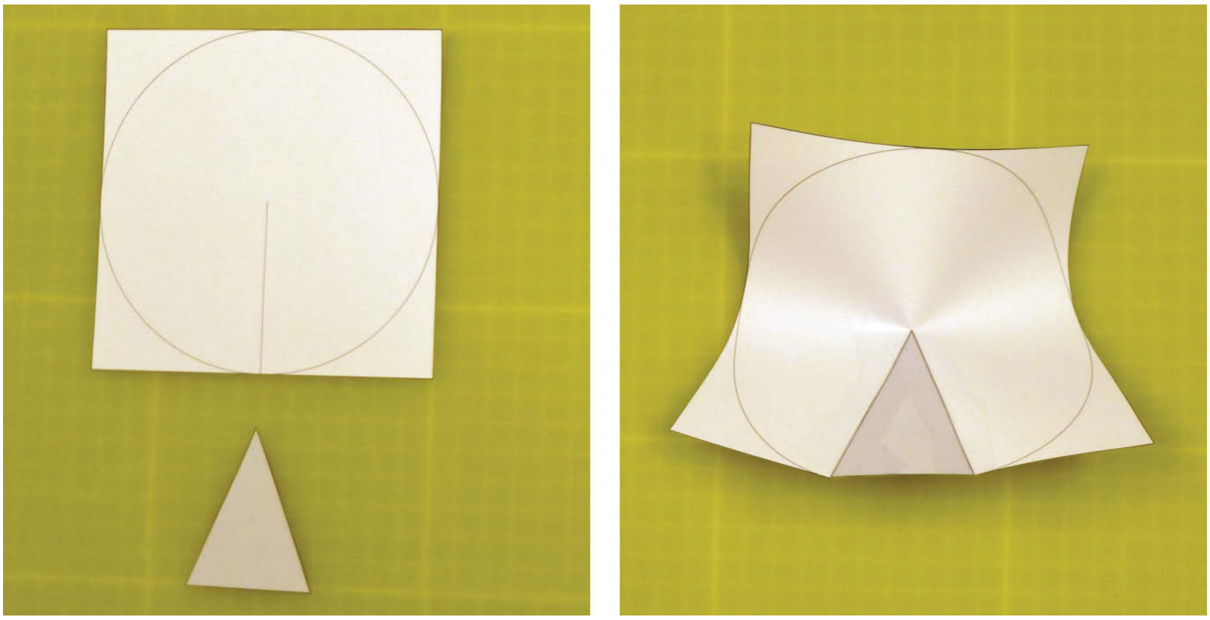
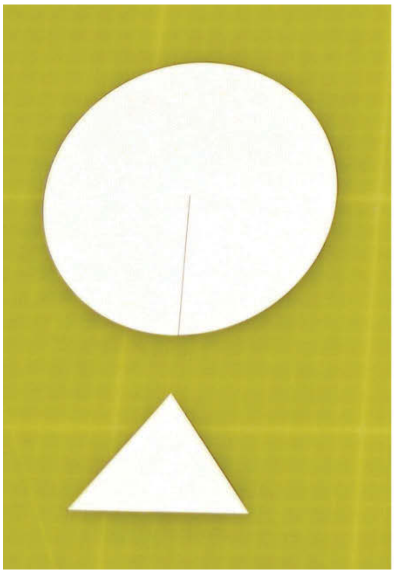


Figure 1: The basic gusset: a triangular gusset inserted into a square shape of material.



A gusset inserted into a circle-shaped pattern.
Flat.

A gusset sewn into a circle-shaped pattern.
Being assembled.

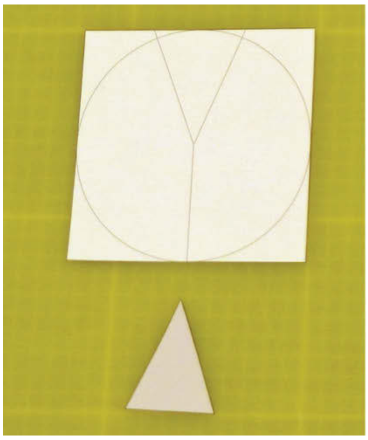
A gusset sewn into a circle-shaped pattern.
In 3D.

Figure 2: To test if the radius size of the gusset location affects gussets, a gusset is sewn into a circular shaped pattern. This ensures that the gussets have a uniform radius.

Results

Part 1: Gusset manipulation on a square pattern

Set 1: Gusset manipulation on the top of pattern

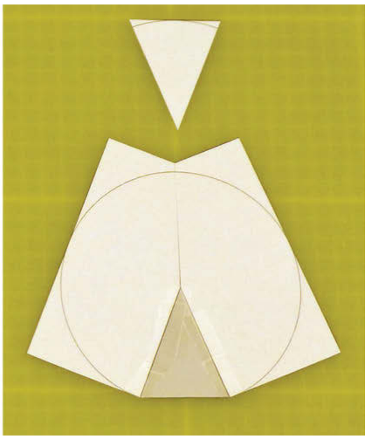


Model 1:

Gusset inserted into a flat square pattern.

Model 2:

A new gusset is drawn on top of the gusset. It has the same size angle as the original gusset.



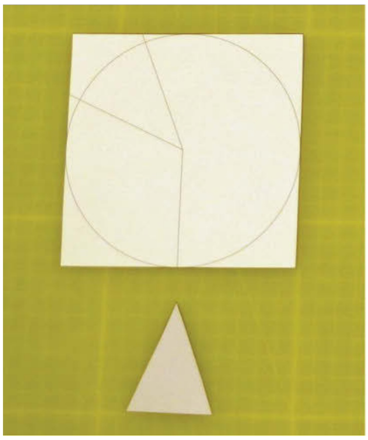
Model 3:

A new gusset is cut out. The gusset is the same size as the original gusset.

Figure 3: A gusset is cut out of the basic dart in a different location. The new gusset is the same size and shape as the original.

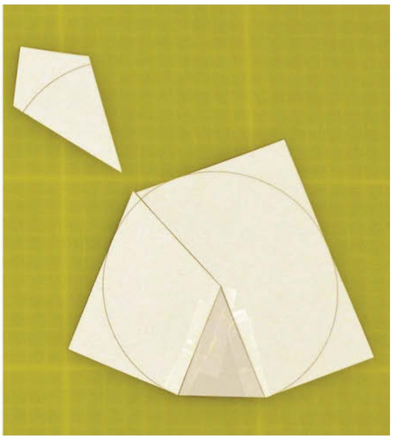
This experiment creates a gusset of identical shape to the original.

Set 2: Gusset manipulation on the top left corner of pattern



Model 4:
A gusset is drawn in a
new location on the basic gusset.

Model 5:
A new gusset is cut out of the
top left corner.

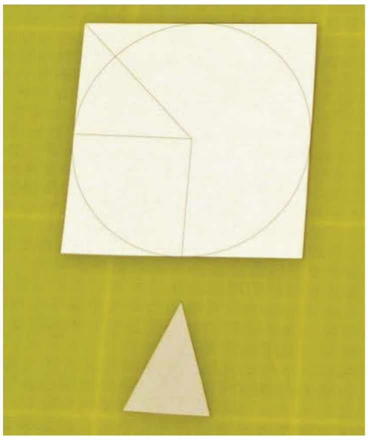


Model 6:
A new gusset is cut out.
This gusset has a kite shape.

Figure 4: Using gusset manipulation, a gusset is cut out of the top left corner of the basic gusset.

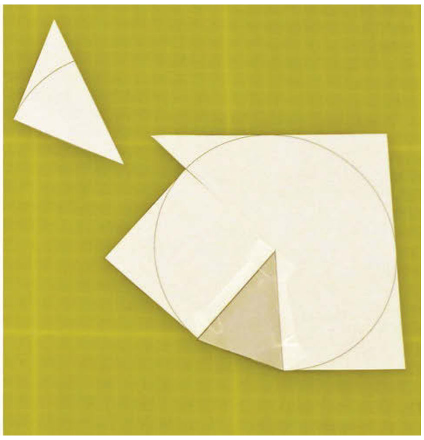
This experiment creates a kite-shaped gusset that is not the same shape as the original.

Set 3: Gusset manipulation on the top left of pattern



Model 7:
A gusset is drawn in a
new location on the basic gusset.

Model 8:
A new gusset is cut out of
the top left corner.

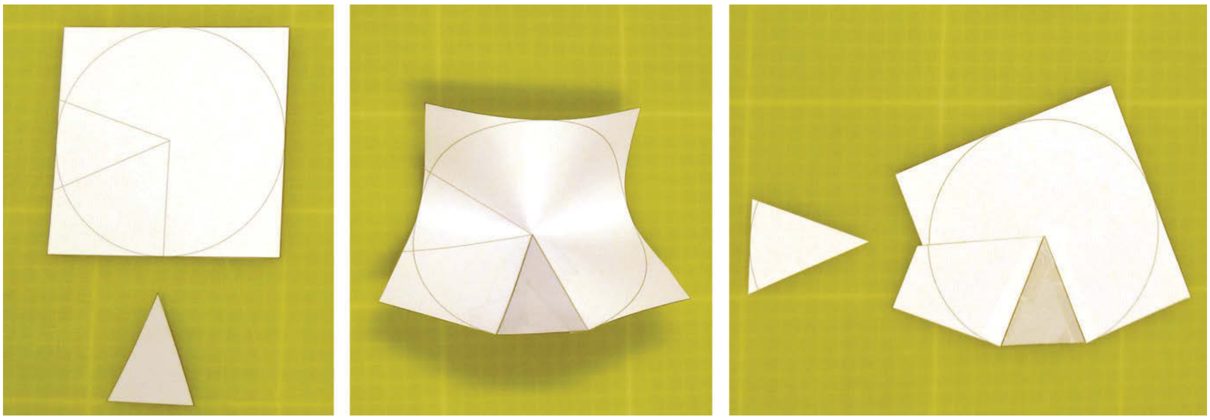


Model 9:
A new gusset is cut out.
This gusset has a triangle shape.

Figure 5: Using gusset manipulation a gusset is cut out of the top left corner of the basic gusset.

This experiment created a right-angled triangular-shaped gusset, not the same shape as the original.

Set 4: Gusset manipulation on the left of pattern



Model 10:
A gusset is drawn in a
new location on the basic gusset.

Model 11:
A new gusset is cut out of the
top left corner.

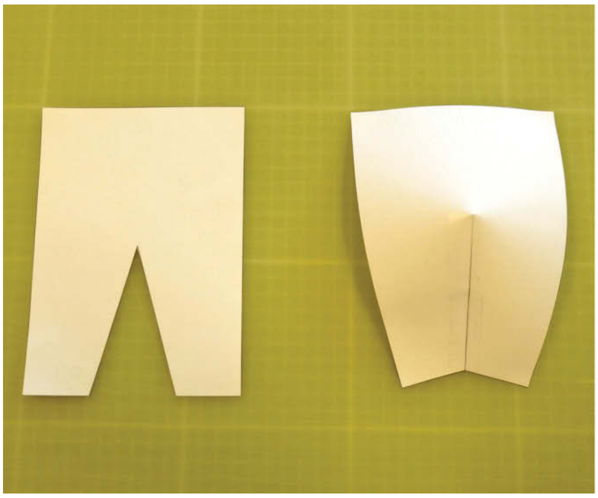
Model 12:
A new gusset is cut out.
This gusset has a triangle shape.

Figure 6: Using gusset manipulation, a gusset is cut out of the top left corner of the basic gusset.

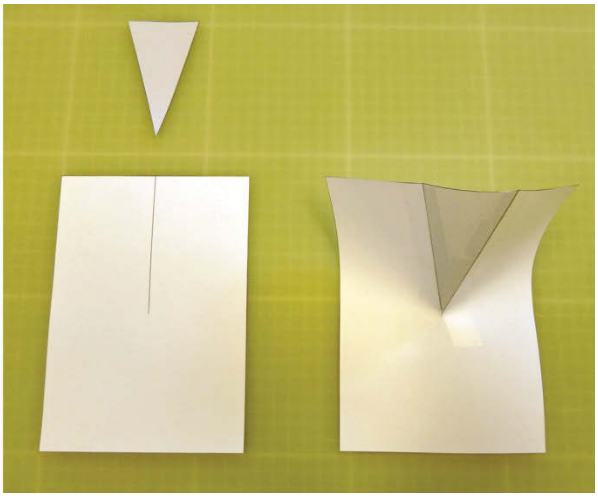
This experiment created a gusset of identical shape to the original.

<u>Observations:</u> From Sets 1 to 4:

It is observed from these four sets of experiments that dart and gusset manipulation have slightly different properties. Gussets create gussets of different shapes when they are moved to different locations, while darts do not seem to have this problem. This may be because darts are a negative space or an absence of material, which gussets are an excess of material (see figure 7). This means that patternmakers need to be aware of the different properties of darts and gussets.



Darts are an absence of material.

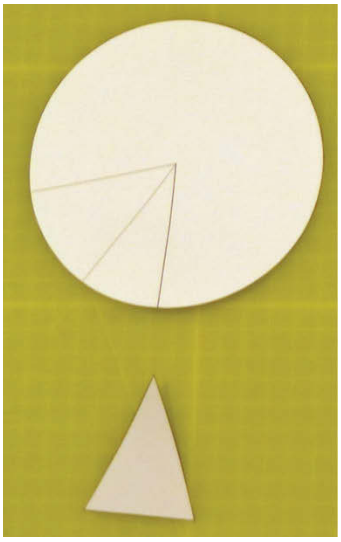


Gussets are an excess of material.

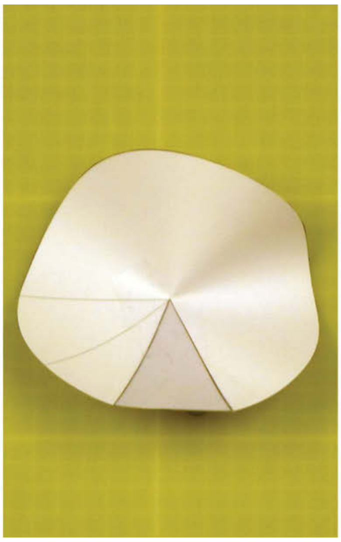
Figure 7: A dart is the absence of material while a gusset is an excess of material.

Part 2: Gusset manipulation on a circular pattern

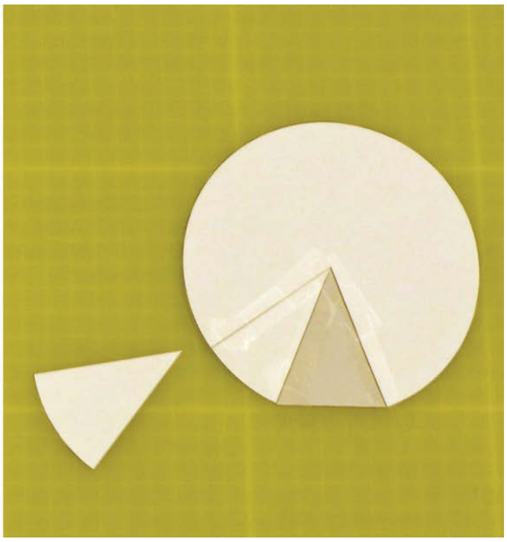
Set 5: Gusset manipulation on the left of pattern.



Model 13:
A gusset inserted into
a circular pattern.



Model 14:
A new gusset being cut out of the
left side of a circular pattern.

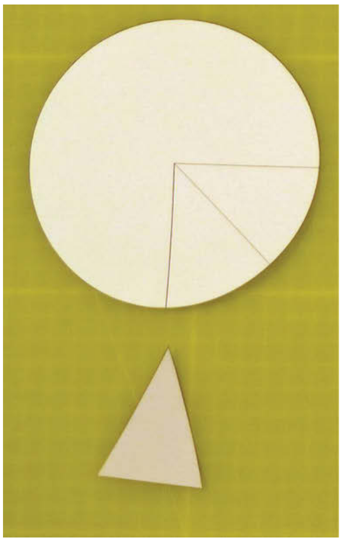


Model 15:
The new gusset is the shape of
a sector of a circle.

Figure 8: Gusset manipulation: cutting a gusset out of the left side of a circular pattern.

This experiment created a gusset of identical shape to the original.

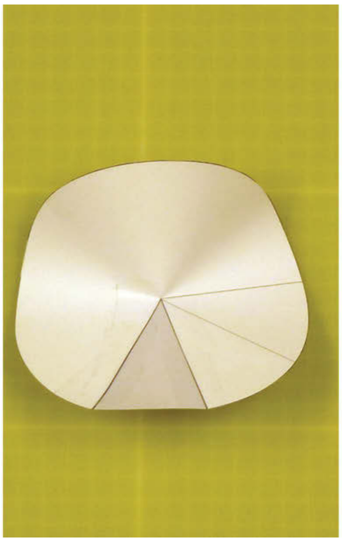
Set 6: Gusset manipulation on the right of pattern



Model 16:

A gusset inserted into

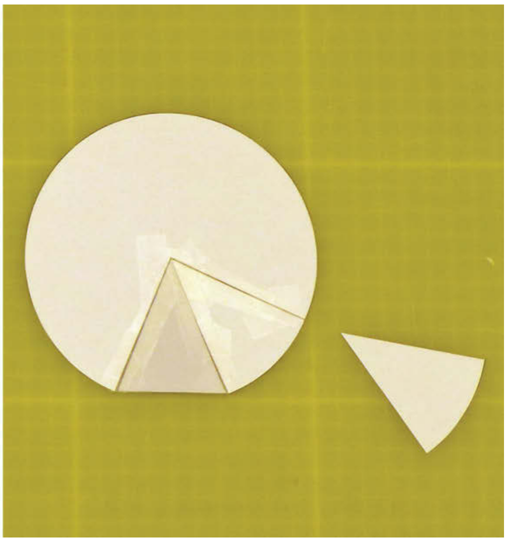
a circular pattern.



Model 17:

A new gusset being cut out of the

right side of a circular pattern.



Model 18:

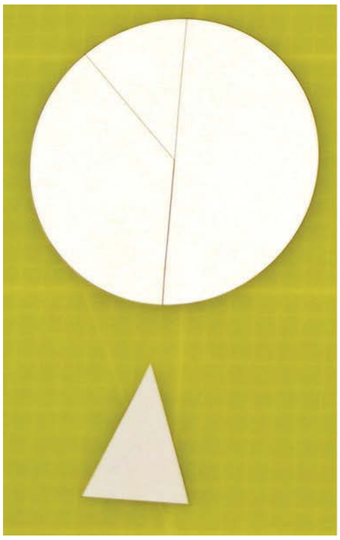
The new gusset is the shape

of a sector of a circle.

Figure 9: Gusset manipulation: Cutting a gusset out of the right side of a circular pattern.

This experiment created a gusset of identical shape to the original.

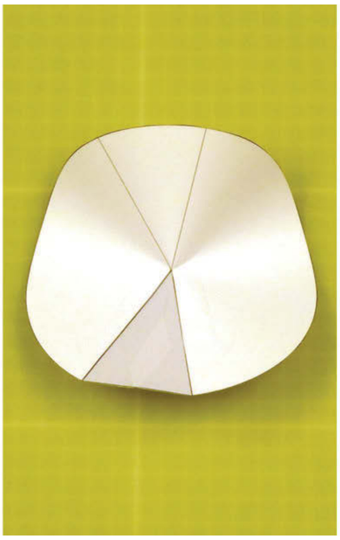
Set 7: Gusset manipulation on the top of pattern



Model 19:

A gusset inserted into

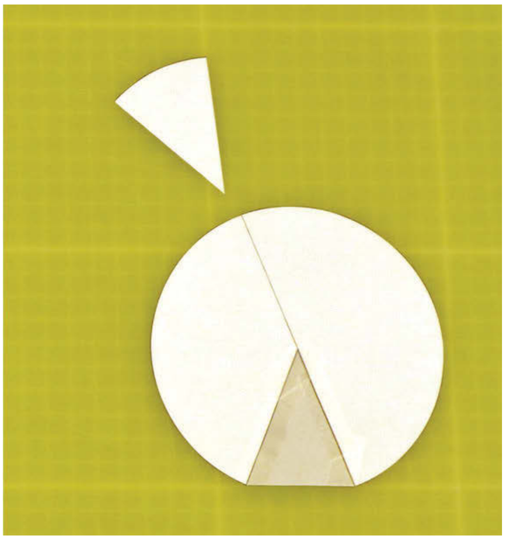
a circular pattern.



Model 20:

A new gusset being cut out of the

top side of a circular pattern.



Model 21:

The new gusset is the shape

of a sector of a circle.

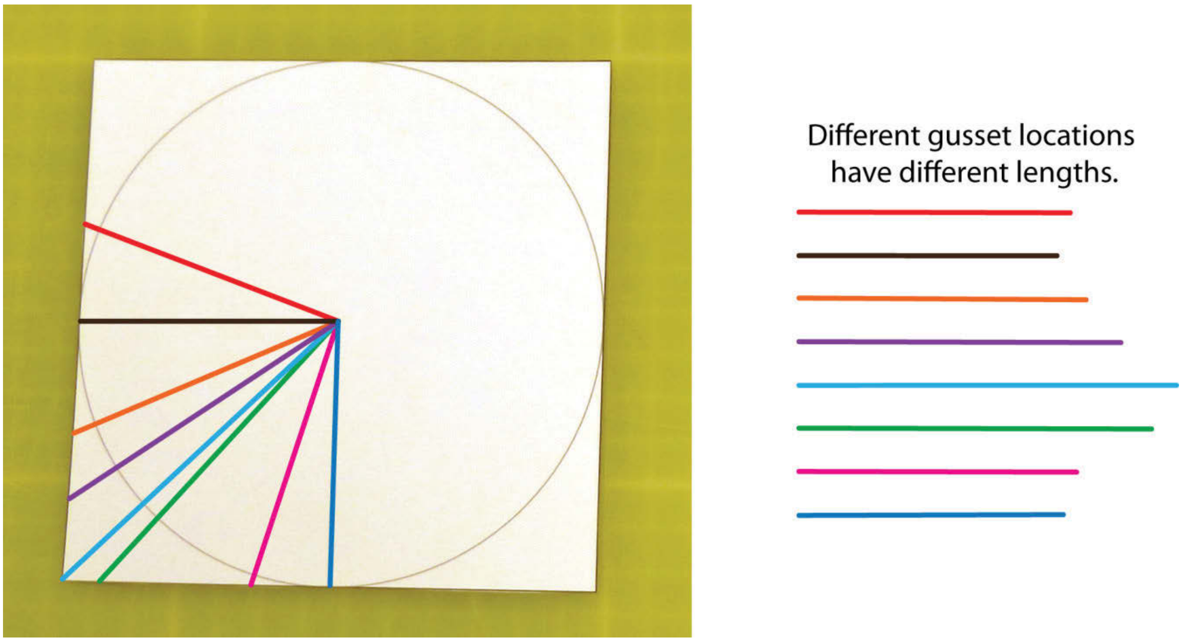
Figure 10: Gusset manipulation: Cutting a gusset out of the top side of a circular pattern.

This experiment created a gusset of identical shape to the original.

<u>Observations</u>: From Sets 5 to 7

In these experiments all the gussets created are identical to the original pattern. The lengths of the gussets are uniform, creating gussets of the same size. There seems to be a correlation between the length of a gusset and its size and shape.

Part 3: Gussets with different lengths

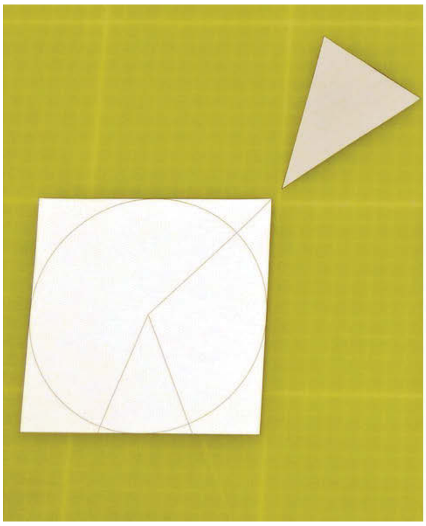


Model 22:

Figure 11: Inserting gussets at different locations on a pattern requires the gussets to be of different lengths.

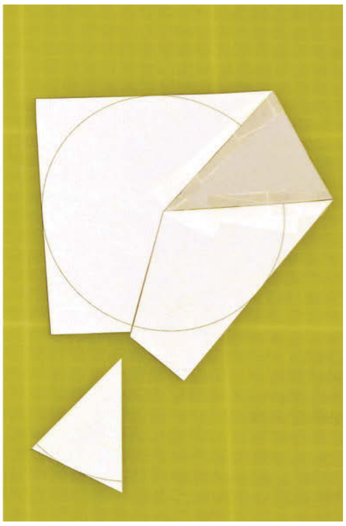
It is observed that placing gussets in different locations creates gussets of different sizes. Some gusset locations create gussets that are much longer than others.

Set 8: Gussets of different radii



Model 23:
A gusset is inserted into the top right corner of the basic gusset pattern.

Model 24:
The inserted gusset is longer than the gusset from the basic dart since the gusset location has a longer radius length.



Model 25:
A new gusset is cut out. It has the same shape as the gusset in the basic gusset.

Figure 12: When sewing a gusset into a different location, the radius of the dart location will determine the gusset's shape and size.

The gusset created in this experiment is a triangle with a longer length than the gusset in Set 1 (see figure 1). This gusset also has the longest gusset length while the gusset in set 1 has the shortest length in this pattern. This demonstrates that gussets with different lengths need gussets of different sizes.

Conclusion

The experiment shows that gusset manipulation has similar yet slightly different properties to dart manipulation. When gussets are manipulated, the location of the new gusset will determine the length of the gusset. Depending on the pattern, different gusset locations can have different lengths. Gusset of different lengths can result in gussets of different sizes and shapes. When initially inserting a gusset into a pattern, the location and length of the gusset will also determine its size and shape.

Experiment 8: A Comparison of the Properties of Darts and Gussets

Rationale

This experiment compares the geometric properties of darts to those of gussets. It observes the properties of these structures by making small alterations to different parts of a pattern and then making observations. These include: changing the size of the cone angle, the length of the cone's radius and the location of the apex point. Darts and gussets are cut into even smaller pieces to observe the properties of each part of the pattern.

Hypothesis

The research anticipates that most of the properties of darts and gussets should be similar, but there may be a small number of aspects that are unique.

Experimental Design

The experiment creates multiple paper models and compares their properties. Two copies of each pattern are created in order to show the pattern as a flat pattern and as a three-dimensional one. Each alteration will be applied to darts and gussets. Through four sets of iterations, each aspect of the pattern is altered and observed. The first part changes the cone angle of the pattern, the second compares patterns with a different-sized radius, the third compares patterns where the apex point of the pattern has been moved, and the fourth dissects darts and gussets into smaller pieces and observes the properties of each part of the pattern.

Procedure

In order to maintain consistency, each of the paper models is constructed in the same way. The paper patterns are created from identical copies of a standard dart block, and are printed from the same digital file on 80 gsm paper. The paper models are carefully cut out and assembled using tape to create a three-dimensional model.

Part 1: Cone Angle

Model 1: Create a circle with radius 6.1 cm and draw a dart of 73°. Leave this as a flat pattern.

Model 2: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 3: Create a circle with radius 6.1 cm and draw a lesser dart of 43°. Leave this as a flat pattern.

Model 4: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 5: Create a circle with radius 6.1 cm and insert a gusset of 73°. Leave this as a flat pattern.

Model 6: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 7: Create a circle with radius 6.1 cm and insert a lesser gusset of 43°. Leave this as a flat pattern.

Model 8: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Observe the properties of these patterns.

Part 2: Radius Size

Model 9: Create a circle with radius 8.8 cm and draw a dart of 43°. Leave this as a flat pattern.

Model 10: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 11: Create a circle with a lesser radius of 6.1 cm and draw a dart of 43°. Leave this as a flat pattern.

Model 12: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 13: Create a circle with radius 8.8 cm and insert a gusset of 43°. Leave this as a flat pattern.

Model 14: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 15: Create a circle with a lesser radius 6.1 cm and insert a gusset of 43°. Leave this as a flat pattern.

Model 16: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Observe the properties of these patterns.

Part 3: Moving the apex

Apex-centred:

Model 17: Create a circle with a radius of 6.1 cm with a dart of 43°.

Model 18: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 19: Create a circle with a radius of 6.1 cm and insert a gusset of 43°.

Model 20: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Apex moved away from centre:

Model 21: Create a circle with a radius of 6.1 cm with a dart of 43°. Then move the apex of the dart 0.8 cm away from the centre and draw a new dart of 50°.

Model 22: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 23: Create a circle with a radius of 6.1 cm and draw a line from the centre to the edge of the pattern. Draw a point on the line which is 0.8 cm away from the centre of the circle. Then cut down this line and insert a gusset of 43°.

Model 24: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Apex moved beyond centre:

Model 25: Create a circle with a radius of 6.1 cm with a dart of 43°. Then move the apex of the dart 0.8 cm beyond the centre and draw a new dart of 39°.

Model 26: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Model 27: Create a circle with a radius of 6.1 cm and draw a line from the centre to the edge of the pattern. Draw a point on the line which is 0.8 cm beyond the centre of the circle. Then cut down this line and insert a gusset of 43°.

Model 28: Create a copy of the last pattern and construct this into a 3D pattern using tape.

Part 4: Dissecting a dart and a gusset

Model 29: Draw a circle with a radius of 6.1 cm. Divide the circle into three parts and draw circles at radius 2.1 cm and 4.7 cm. Then draw a dart of 43° on the pattern. Leave this as a flat pattern.

Model 30: Create a copy of the model 29 and cut the cone along the circular lines to create three different sections.

Model 31: Recreate model 29 and construct the pattern in 3D using tape.

Model 32: Recreate model 30 and construct the pattern in 3D using tape.

Model 33: Draw a circle with a radius of 6.1 cm. Divide the circle into three parts and draw circles at radius 2.1 cm and 4.7 cm. Insert a gusset 43° and mark out radius lines of 2.1 cm and 4.7 cm on the pattern. Leave this as a flat pattern.

Model 34: Create a copy of model 33 and cut the cone along the circular lines to create three different sections.

Model 35: Recreate model 33 and construct the pattern in 3D using tape.

Model 36: Recreate model 34 and construct the pattern in 3D using tape.

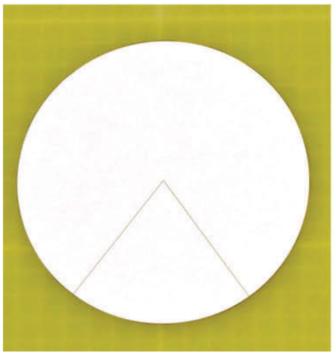
Results

Part 1: Cone Angle

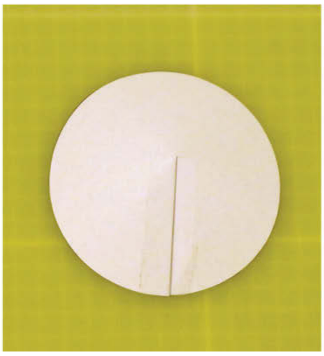
Set 1: Darts and gussets with different sized cone angles

DARTS

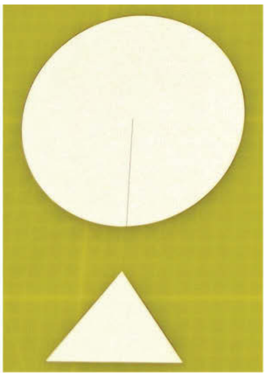
GUSSETS


Flat Pattern

Model 1:
Dart with greater dart angle.


3D Pattern

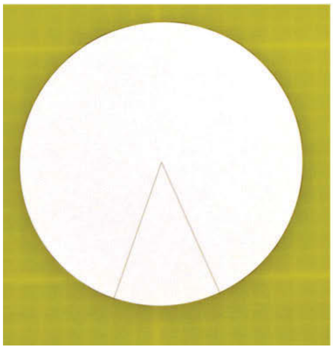
Model 2:
Dart with greater dart angle.


Flat Pattern

Model 5:
Gusset with lesser dart angle.


3D Pattern

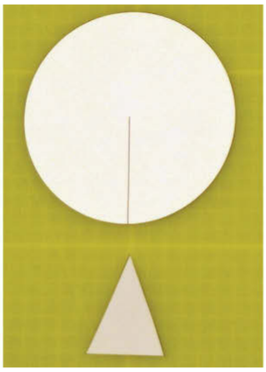
Model 6:
Gusset with lesser dart angle.


Flat Pattern

Model 3:
Dart with lesser dart angle.


3D Pattern

Model 4:
Dart with lesser dart angle.


Flat Pattern

Model 7:
Gusset with lesser dart angle.

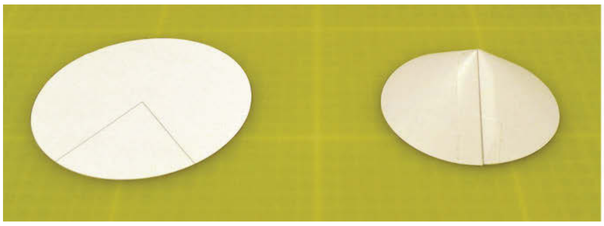

3D Pattern

Model 8:
Gusset with lesser dart angle.

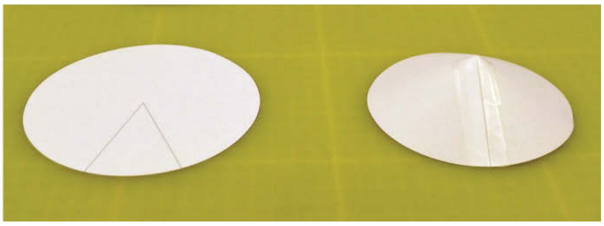
Figure 1: Dart and gussets with angles of different sizes.

Observation

Darts of different dart angles sizes create cones of different heights. Darts with a greater dart angle create a taller cone while darts with a lesser angle creates a shorter cone (see figure 2). Gussets with different gusset angles create hyperbolic shapes of different sizes.



A dart with a greater dart angle creates a taller cone.



A dart with a lesser dart angle creates a shorter cone.

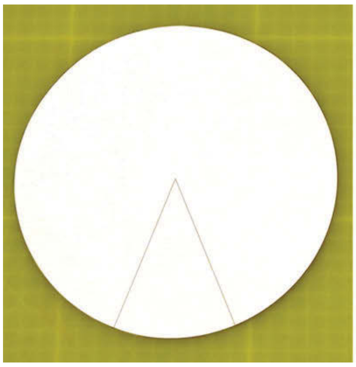
Figure 2: The properties of darts. Dart angle affects the cone height. The greater the dart angle the taller the cone.

<u>Part 2</u>: Radius Size

Set 2: Darts and gussets with different sizes of radius.

DARTS

GUSSETS

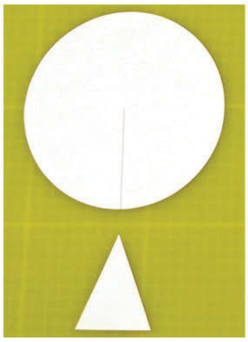


Flat Pattern

Model 9:
Dart with greater radius.

3D Pattern

Model 10:
Dart with greater radius.

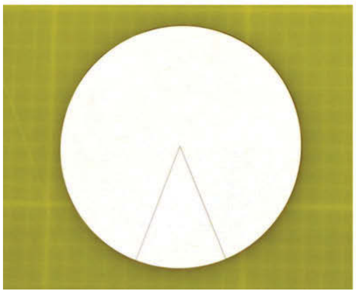


Flat Pattern

Model 13:
Dart with lesser radius.

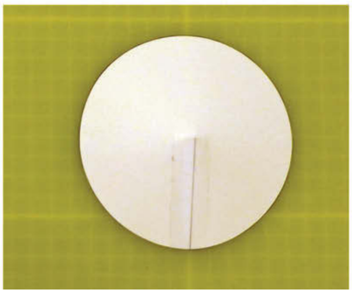
3D Pattern

Model 14:
Dart with lesser radius.



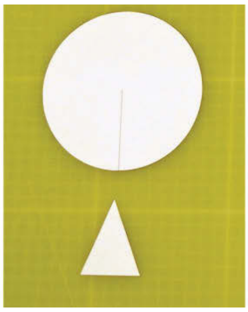
Flat Pattern

Model 11:
Dart with lesser radius.



3D Pattern

Model 12:
Dart with lesser radius.



Flat Pattern

Model 15:
Dart with lesser radius.

3D Pattern

Model 16:
Dart with lesser radius.

Figure 3: Dart and gussets with different-sized radii.

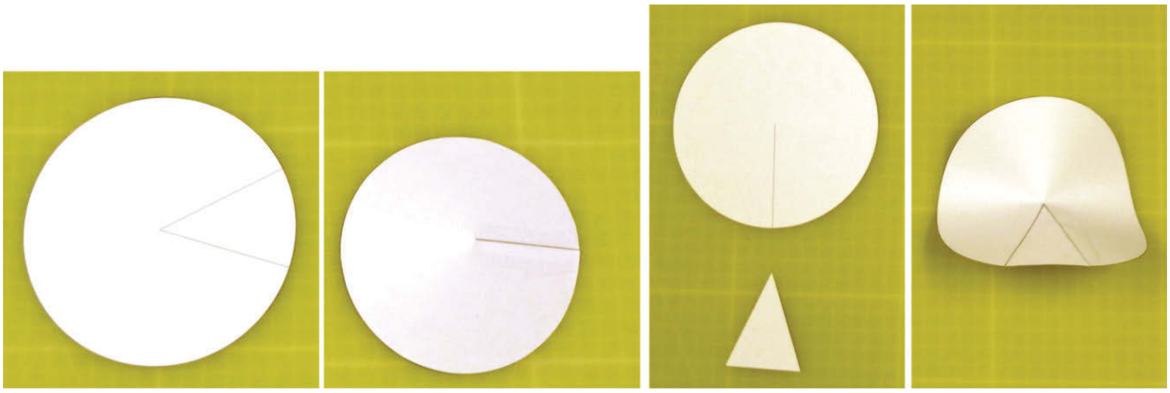
Observations

Darts that have radii of different sizes are similar in shape. The cone with the smaller radius can be mounted on top of the cone with the larger radius, as they have the same dart angle. The same can be done by placing the smaller gusset on top of the larger gusset.

Part 3: Moving the apex

Set 3: Moving the apexes of darts and gussets

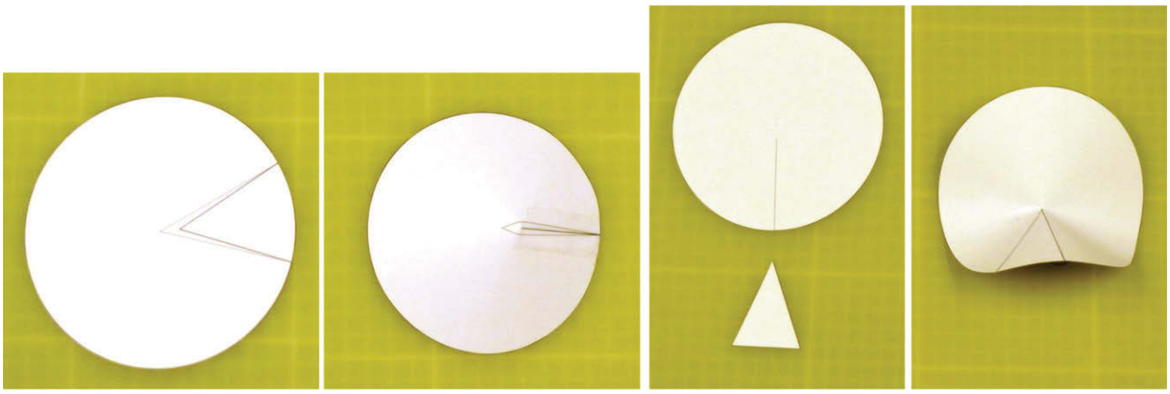
DARTS GUSSETS



Flat pattern	3D pattern	Flat pattern	3D pattern
Model 17: Dart with apex at centre.	Model 18: Dart with apex at centre.	Model 19: Gusset with apex at centre.	Model 20: Gusset with apex at centre.

Figure 4: Apex point centred.

DARTS GUSSETS

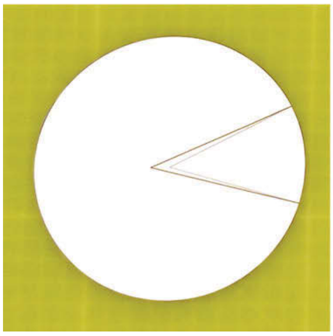


Flat pattern	3D pattern	Flat pattern	3D pattern
Model 21: Dart with apex moved away from the centre.	Model 22: Dart with apex moved away from the centre.	Model 23: Gusset with apex moved away from the centre.	Model 24: Gusset with apex moved away from the centre.

Figure 5: Apex points moved away from the centre.

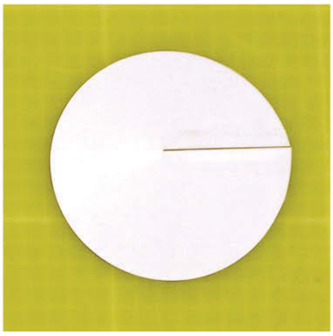
DARTS

GUSSETS



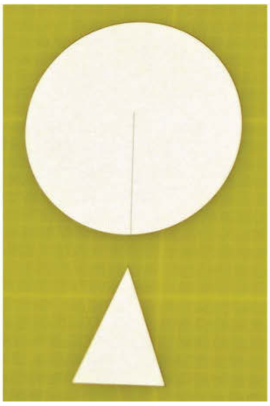
Flat Pattern

Model 25:
Dart with apex moved
beyond centre.



3D Pattern

Model 26:
Dart with apex moved
beyond centre.



Flat Pattern

Model 27:
Gusset with apex moved
beyond centre.

3D Pattern

Model 28:
Gusset with apex moved
beyond centre.

Figure 6: Apex points moved beyond the centre.

Part 4: Dissecting a dart and a gusset

Set 4: Dissecting darts and gussets

DARTS

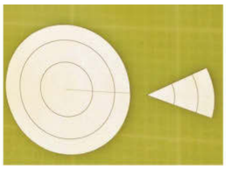
GUSSETS

Flat Pattern

Model 29:
A cone with a dart
divided in three parts.

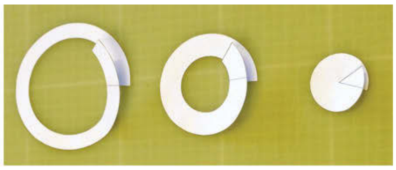
Flat Pattern

Model 30:
A cone with a dart cut into three
different pieces.



Flat Pattern

Model 33:
A cone with a gusset
divided in three parts.

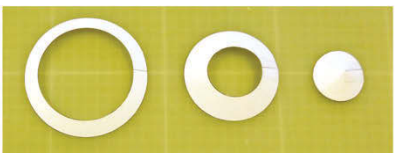


Flat Pattern

Model 34:
A cone with a gusset cut into three
different pieces.

3D Pattern

Model 31:
A cone with a dart
divided in three
parts.

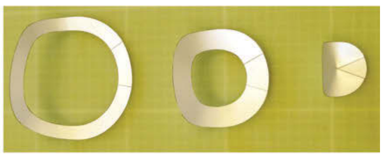


3D Pattern

Model 32:
A cone with a dart cut into three
different pieces.

3D Pattern

Model 35:
A cone with a gusset
divided in three parts.



3D Pattern

Model 36:
A cone with a gusset cut into three
different pieces.

Figure 7: Dart and gussets dissected and separated into their components.

Observations

When the cones are dissected into smaller pieces, the pieces of the cone retain the properties of the original cone (see figure 8). On a dart the tip of the cone becomes a small cone with the same cone angle, and the other parts of the cone become frustums with the same cone angles as the original cone (see figure 9). The same applies to gussets.

DARTS GUSSETS

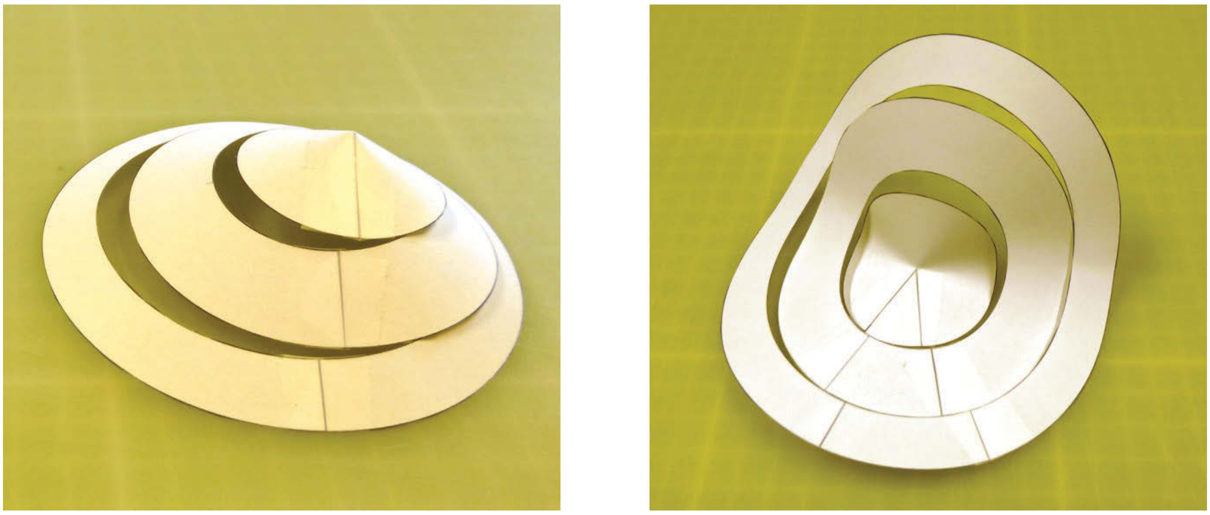
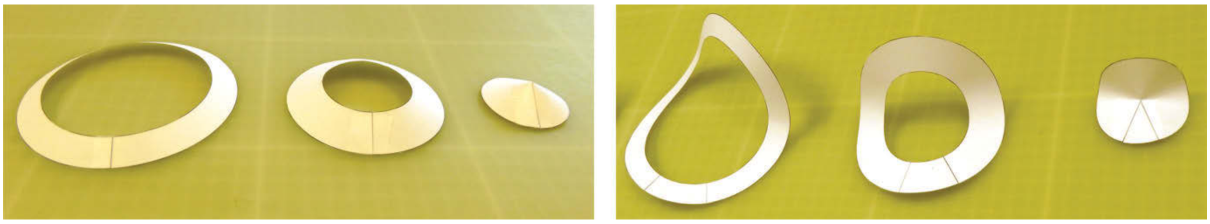


Figure 8: Dart and gussets can be cut into smaller pieces.



Their components still have the properties of darts and gussets.

Figure 9: When a dart or gusset is dissected into different components the parts have the geometric properties of the original garment.

Conclusion

Darts and gussets have similar but slightly differing properties. Changing the cone angles of darts and gusset affects their shape. This in turn affects the cone height of darts, which can easily be measured in darts. However, it is not possible to measure the cone height of gussets in the same way. This is because gussets form hyperbolic shapes which are not cone-shaped. Changing the radius of a cone affects both darts and gussets in a similar manner. Moving the location of the apex changes the shape of both darts and gussets. In darts, it tends to tilt the angles of the cone, a property that cannot be measured the same way in gussets. When cutting up darts and gussets, the tip of the cone becomes a small version of the cone while the frustums of the cone maintain the geometric properties of the original cone.

3. Complex Darts

Experiment 9: **Complex darts: diamond darts**

Experiment 10: **Concave and convex darts**

Experiment 11: **Concave and convex gussets**

Experiment 12: **Designing on complex darts**

Aim

This set of experiments explores the properties of complex darts, namely: darts that have multiple apex points on a single dart leg. Complex darts come in a variety of shapes. The experiments show how diamond darts shape a pattern differently compared to simple darts, and explore how darts with curved edges can be deconstructed into a simpler series of apex points with darts and gussets. It also analyses darts of convex and concave shapes to find how their structure affects their three-dimensional form, a process then applied to convex and concave gussets. From there, it examines how to create style lines on structures with complex darts while maintaining the same three-dimensional shape as the original garment.

Method

The first experiment in the set examines the unique properties of diamond-shaped darts, while the second offers a way to deconstruct complex darts into a series of apex points with darts or gussets. This technique is then used to analyse curved darts with convex and concave shapes. The third experiment uses the same technique to deconstruct gussets of convex and concave shapes into a series of simpler darts and gussets, and the final experiment examines a technique for designing different-shaped style lines on curved darts and gussets that retain the three-dimensional form of the garment.

Analysis

In sum, these experiments demonstrate a technique whereby complex darts and gussets can be deconstructed to reveal how they alter the pattern's 3D form. Diamond darts are distinctive in that they create a gusset in the centre of the dart. In effect, they create two darts and a gusset at the centre.

Using a combination of dart and gusset manipulation on the pattern it is possible to deconstruct complex darts into a series of darts and gussets. In particular, concave darts can be deconstructed into a series of darts and gussets. Meanwhile, complex gussets have similar properties to complex darts. A convex-shaped gusset creates a series of darts, while a concave-shaped gusset creates a series of darts and gussets. Significantly, the final experiment in the group shows how it is possible to draw a style line that maintains the original shape of the garment provided it passes through all the style lines of the dart.

Experiment 9: Complex Darts: Diamond Darts

Rationale

This experiment aims to understand the properties of diamond-shaped darts. These darts are more complex as they have multiple apex points. Darts with more than one apex point are referred to by the research as "complex" darts, in relation to "simple" darts that have a single apex. Simple darts make patterns more spherical in geometry. Diamond darts are often used in garments around the waist, and make patterns more hyperbolic in shape. This experiment aims to understand the structure and function of diamond-shaped darts by deconstructing them into their components.

Hypothesis

The research anticipates that diamond-shaped darts will shape a pattern into a hyperbolic shape, based on the idea that diamond shaped darts are used in hyperbolic-shaped parts of the body.

Experimental Design

The experiment analyses the structure and function of each of the apex points of a diamond dart in order to analyse the properties of a pattern. It involves taking the pattern in three-dimensions and flattening it as a series of darts and gussets. The process involves a combination of dart and gusset manipulation. Through a series of iterations, it analyses complex darts of different shapes. It starts with a diamond dart and moves on to more complex diamond-shaped darts.

Procedure

All models should be printed onto 80 gsm paper from a digital file.

Set 1: Diamond darts

Model 1: Create a paper model with a diamond shaped dart. Leave as a flat pattern.

Model 2: Construct the pattern 3D using tape.

Model 3: Cut a straight line from the base of the pattern to the apex on the base of the pattern.

Model 4: Cut a straight line from the bottom apex to the apex point in the middle of the pattern.

Model 5: Cut a straight line from the top of the pattern to the top apex point.

Make observations and try to find out how the darts are making the pattern hyperbolic in shape.

Set 2: Three point diamond dart

Model 6: Create a paper model with a three-pointed diamond dart pattern (see figure 1). Leave as a flat pattern.

Model 7: Construct the pattern 3D using tape.

Model 8: Cut a straight line from the top of the pattern to the top apex of the pattern.

Model 9: Cut a straight line from the top apex to the apex in the middle of the pattern.

Model 10: Cut a straight line from the right side of the pattern to the apex on the right of the pattern.

Model 11: Cut a straight line from the left side of the pattern to the apex on the left of the pattern.

Make observations about these patterns.

Set 3: Four point diamond dart

Model 12: Create a paper model with a four-point diamond dart pattern (see figure 2). Leave as a flat pattern.

Model 13: Construct the pattern 3D using tape.

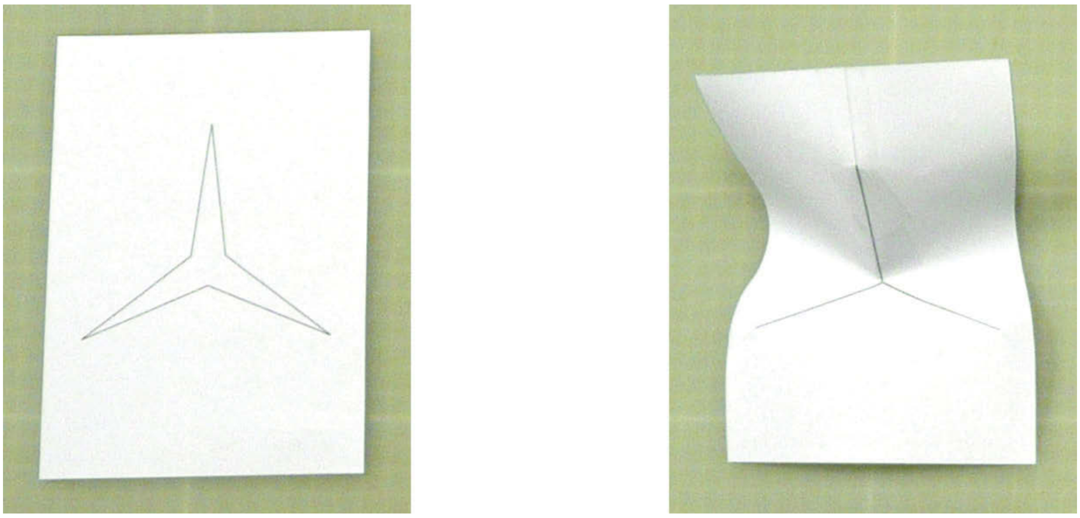
Model 14: Cut a straight line from the top of the pattern to the top apex of the pattern.

Model 15: Cut a straight line from the top apex to the apex in the middle of the pattern.

Model 16: Cut a straight line from the right side of the pattern to the apex on the right of the pattern. Then cut a straight line from the left side of the pattern to the left apex of the pattern.

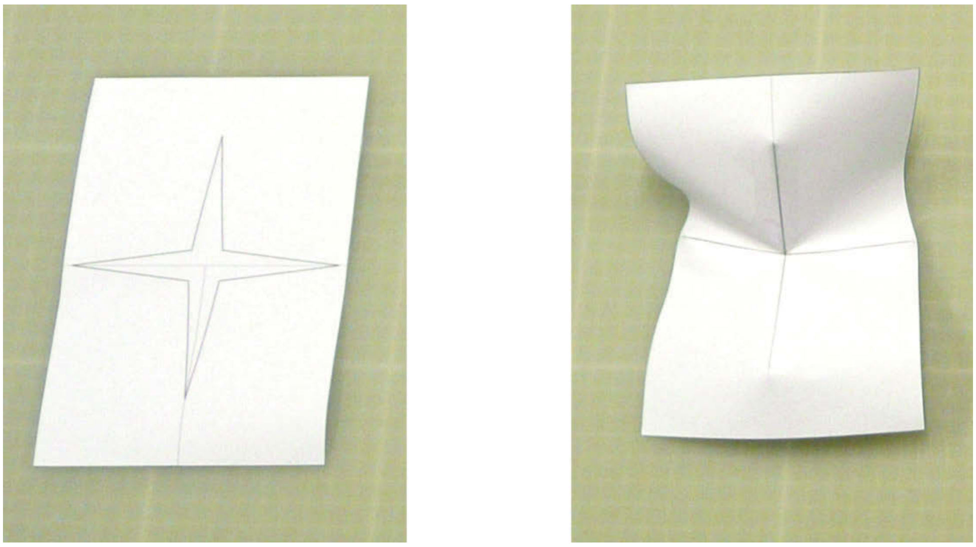
Model 17: Cut a straight line from the base of the pattern to the base apex of the pattern.

Make observations about these patterns.



Flat Pattern 3D Pattern

Figure 1: A three point diamond dart.

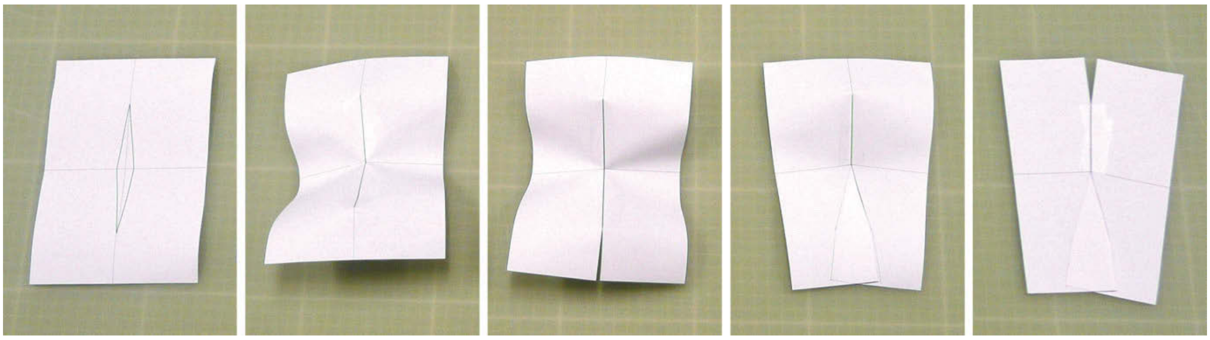


Flat Pattern 3D Pattern

Figure 2: A four point diamond dart.

Results

Set 1: Diamond dart



Model 1:
Diamond dart as a flat pattern.

Model 2:
Diamond dart constructed in three-dimensions.

Model 3:
A straight line is cut from the bottom to the first apex, revealing a dart.

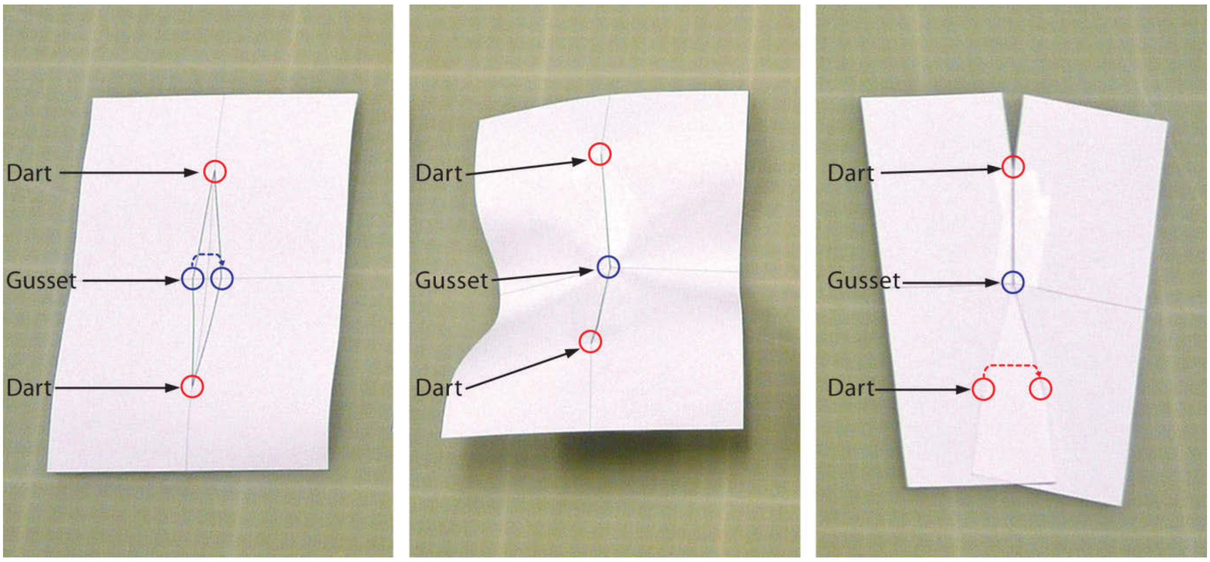
Model 4:
A straight line is cut from the bottom to the next apex, revealing a gusset.

Model 5:
A straight line is cut from the top to the final apex, revealing a dart.

Figure 3: Constructing and flattening a diamond dart.

Observations

The top and base apexes create darts, while the apex in the middle creates a gusset (see figure 3). The gusset in the middle apex is the effect that makes the pattern hyperbolic in shape.
It appears that the combination of darts pivot the pattern so that a gusset is created. When the top dart is closed the shape of the dart creates an asymmetrical dart leg (see figure 4). This asymmetrical dart leg creates a gusset.

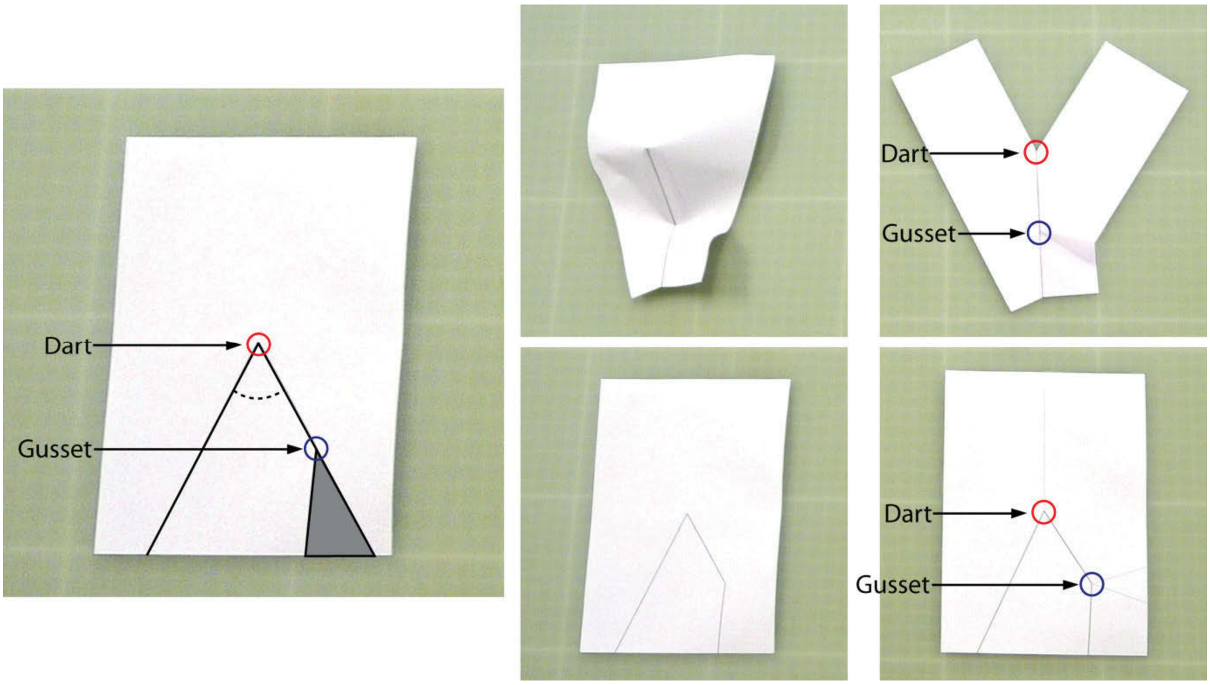


Diamond dart flat pattern.

Diamond dart constructed in three-dimensions.

Diamond dart deconstructed into a flat pattern.

Figure 4: A summary of the properties of a diamond dart. Two darts and a gusset are created by a diamond dart.



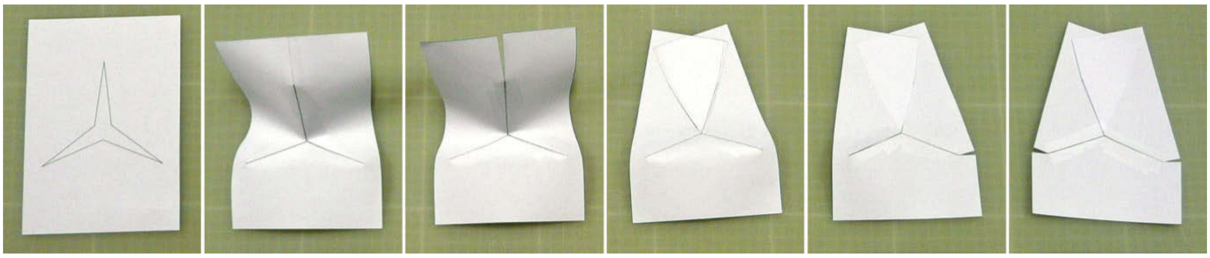
An asymmetrical dart creates a gusset. The gusset is the shaded area.

An asymmetrical dart flat and in 3D.

Deconstructing an asymmetrical dart into darts and gussets.

Figure 5: Asymmetrical dart legs can create a gusset.

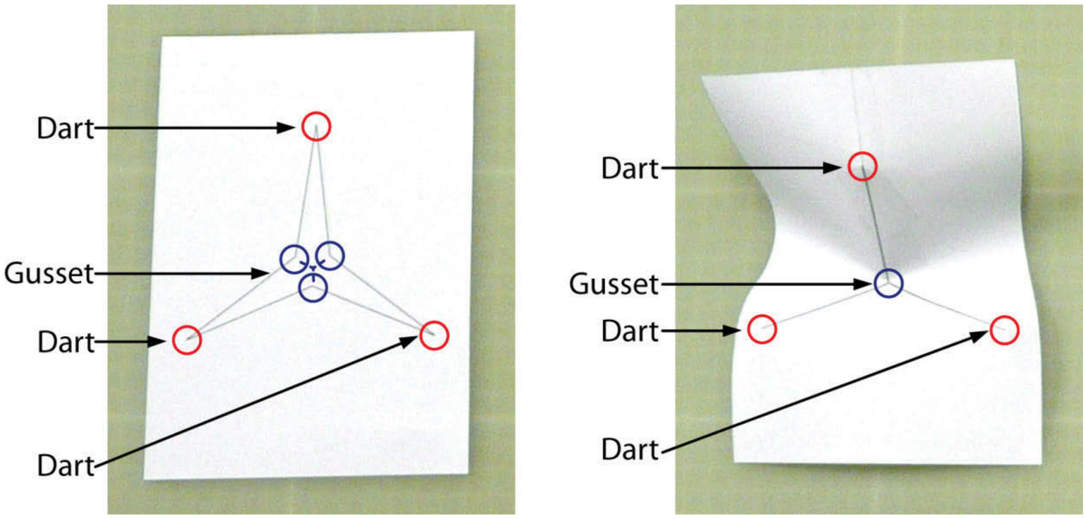
Set 2: Three point diamond dart



Model 6:	Model 7:	Model 8:	Model 9:	Model 10:	Model 11:
Diamond dart Flat pattern.	Diamond dart In 3D.	A straight line is cut from the top edge to the first apex, revealing a dart.	A straight line is cut from the first apex to the centre of the dart, revealing a gusset.	A straight line is cut from the right edge the next apex, revealing a dart.	A straight line is cut from the left edge to the next apex, revealing a dart.

Figure 6: A three point diamond dart is flattened and deconstructed into a series of darts and gussets.

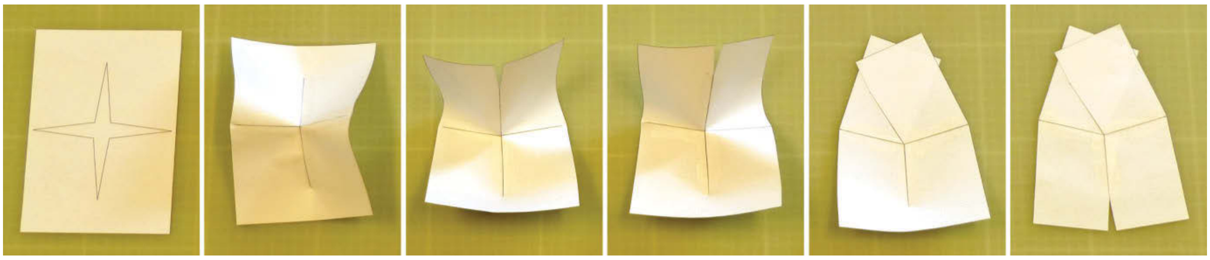
This experiment creates a pattern with three darts on the outside, and an apex point in the centre that creates a gusset. The size of this gusset can be observed as the overlap in the central apex in figure 5.



Flat Pattern 3D Pattern

Figure 7: A three point diamond dart can be deconstructed into a series of darts and gussets.

Set 3: Four point diamond dart



Model 12: Four point diamond dart. Flat pattern.

Model 13: Four point diamond dart in 3D.

Model 14: A straight line is cut from the top edge to the first apex, revealing a dart.

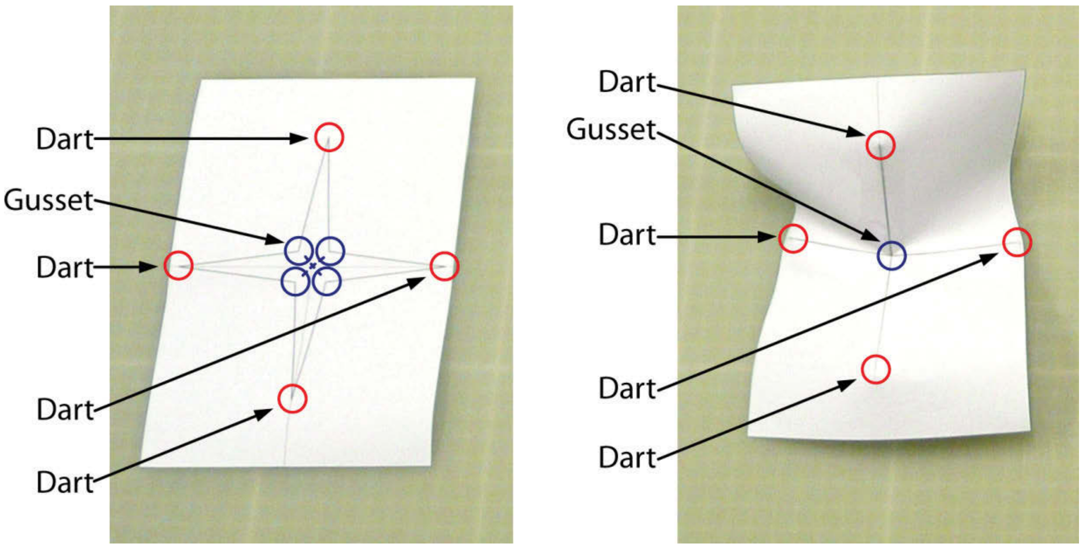
Model 15: A straight line is cut from the first apex to the centre of the dart, revealing a gusset.

Model 16: Straight lines are cut from the right and left edges to the apexes, revealing darts on the right and left.

Model 17: A straight line is cut from the bottom edge to the apex, revealing a dart.

Figure 8: A four point diamond dart can be deconstructed into a series of darts and with a gusset at the central point.

This experiment creates a pattern with four darts on the outside and an apex point in the centre that creates a gusset. The size of this gusset can be observed as the overlap in the central apex in figure 8.



Flat pattern

3D pattern

Four point diamond dart deconstructed into darts and gussets.

Four point diamond dart deconstructed into darts and gussets.

Figure 9: Four point diamond darts deconstructed into darts and gussets.

Conclusion

Diamond darts create the effect of a gusset in the middle part of the dart. Diamond darts display mirror symmetry instead of rotational symmetry. When the outer darts are closed they make the dart leg asymmetrical. This creates a wedge shape, generating a gusset. This allows darts in a diamond configuration to create gusset-like effects.

Experiment 10: Concave and Convex Darts

Rationale

This experiment analyses the geometric properties of curved darts by deconstructing them into a series of darts and gussets. This is achieved by using a combination of dart manipulation and gusset manipulation. Hereby, it analyses concave and convex shaped darts. This technique is based on the idea that a curved shape can be deconstructed into a series of smaller straight line tangent points (see figure 1). Taking curves and turning them into tangent lines makes it easier to identify and manipulate these patterns.

Hypothesis

The research anticipates that the concave and convex darts can be deconstructed into a series of smaller darts.

Experimental Design

The experiment explores the properties of curved darts that are concave and convex in shape. It takes curves and deconstructs them into a series of straight lines with apex points. These apex points are then manipulated to reveal whether they create darts or gussets. The experiment allows us to analyse the structure and function of each part of these curves. The first part of the experiment will analyse convex darts and the second will analyse concave darts.

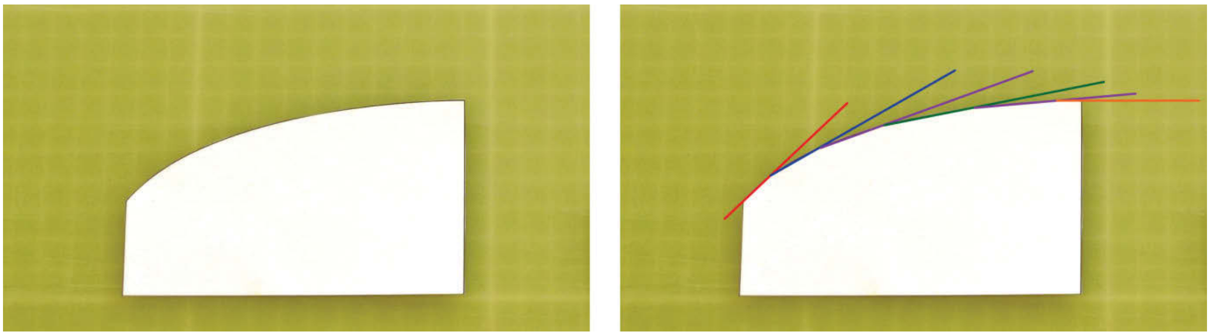


Figure 1: The curved edge of the pattern can be divided into a series of tangent lines.

Procedure

The experiment consists of two sets of experiments.

Set 1: Convex darts

The aim of this experiment is to take a curved convex dart pattern and flatten its seam line into a series of darts and gussets. Start with a pattern of a convex dart printed from the same digital file on 80 gsm paper. The dart has tangent lines drawn on the curve which deconstructs the pattern into a series of apex points and straight lines. In this pattern each curve is composed of three straight lines. Drawing these tangent lines will make it easier to manipulate the patterns and visually demonstrate the transformation.

Model 1: Start with the convex dart pattern.

Model 2: Cut a line from the left side of the pattern to the first apex point on the left side of the pattern. Pivot this pattern piece so that the edge of the curve aligns with the straight edge of the curve next to it.

Model 3: Cut a line from the left side of the pattern to the second apex point on the left side of the pattern. Pivot this pattern piece so that the edge of the curve aligns with the straight edge of the curve next to it.

Model 4: Cut a line from the top of the pattern to the central apex point on the top of the pattern. Pivot this pattern piece so that dart in the centre of the pattern is closed.

Model 5: Cut a line from the right side of the pattern to the second apex in the middle of the pattern. Pivot this pattern piece so that the edge of the curve aligns with the straight edge next to it.

Model 6: Cut a line from the right side of the pattern to the first apex on the right side of the pattern. Pivot this pattern piece so that the edge of the curve aligns with the straight edge next to it.

This process straightens the curved seam line and deconstructs the pattern into a series of darts and gussets. Analyse the darts created by this pattern.

Set 2: Concave darts

The aim of this experiment is to take a curved concave dart pattern and flatten its seam line into a series of darts and gussets. Start with a pattern of a convex dart printed from the same digital file on 80 gsm paper. The dart has tangent lines drawn on the curve which deconstructs the pattern into a series of apex points and straight lines. In this pattern each curve is composed of three straight lines.

Model 7: Start with the concave dart pattern.

Model 8: Start at the apex point on the bottom right side of the curve. Pivot the apex point of the pattern piece so that the edge of the curve aligns with the straight edge next to it. If this pattern is a gusset, pinch out the gusset and fold the pattern flat.

Model 9: Start at the apex point in the middle of the right side of the curve. Pivot the apex point using gusset manipulation so that the edge of the curve aligns with the straight edge next to it.

Model 10: Cut a line from the top of the pattern to the central apex point on the top of the pattern. Pivot this pattern piece so that the dart in the centre of the pattern is closed.

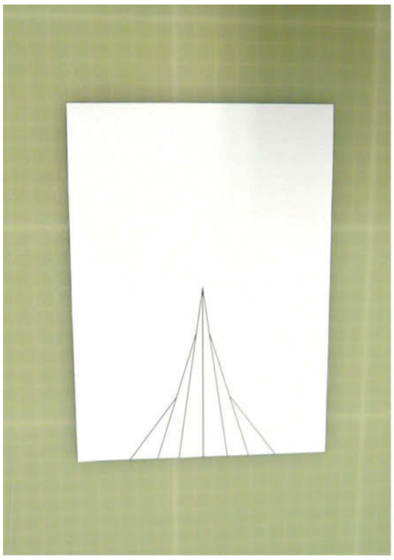
Model 11: Pivot the apex point in the middle of the left side of the pattern to straighten the curved edge of the pattern.

Model 12: Pivot the apex point in the bottom of the left side of the pattern to straighten the curved edge of the pattern.

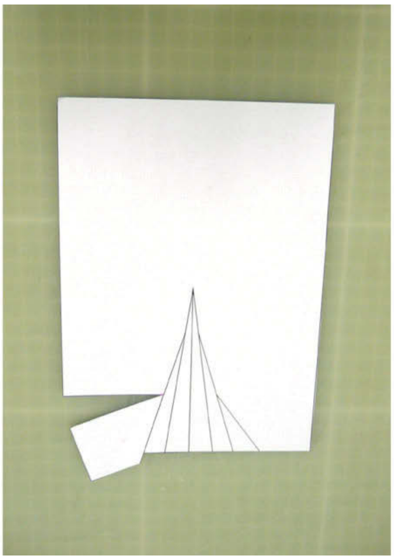
This process straightens the curved seam line and deconstructs the pattern into a series of darts and gussets. Analyse the darts created by this pattern.

Results

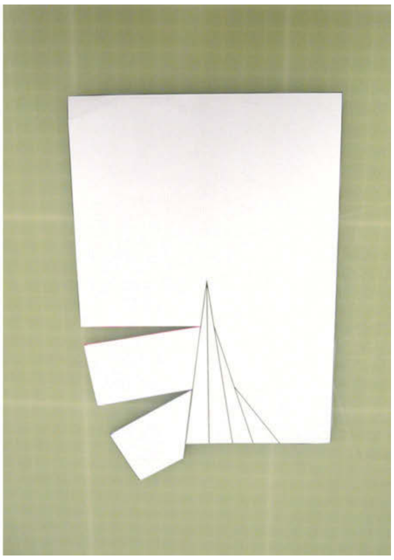
Set 1:



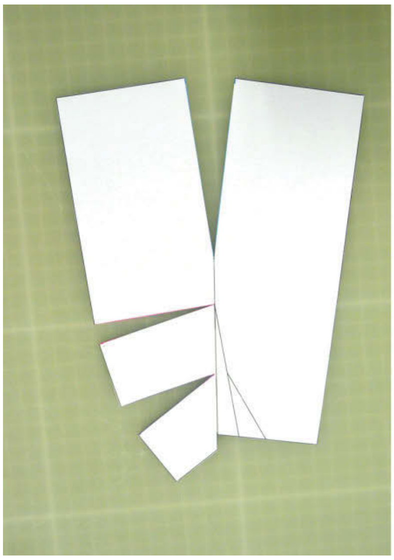
Model 1:
Convex dart flat pattern.
The curved dart is divided into
a series of straight tangent lines.



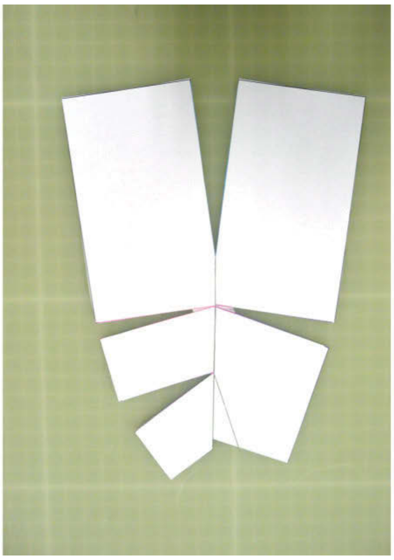
Model 2:
The apex point is pivoted
to create a straight dart leg.
This creates a dart.



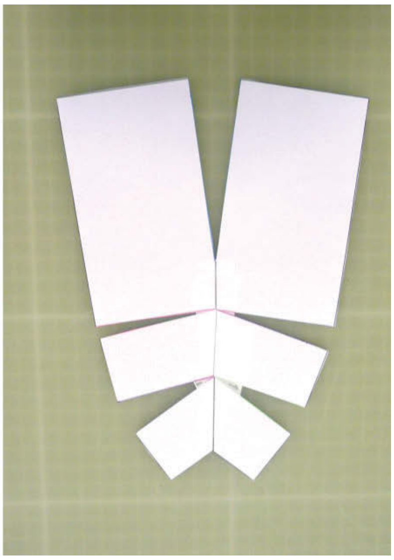
Model 3:
The next apex point is pivoted
to straighten the dart leg.
This creates a dart.



Model 4:
The central apex point is pivoted
to close the central dart.
This creates a dart.



Model 5:
The next apex point is pivoted
to create a straight dart leg.
This creates a dart.

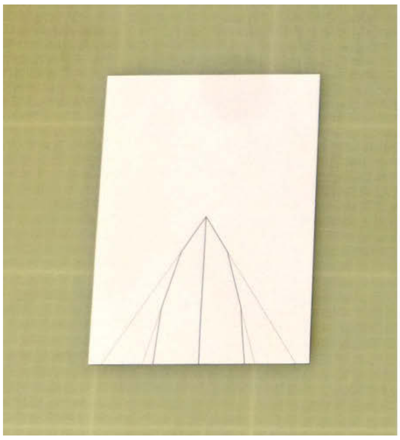


Model 6:
The apex final point is pivoted
to close the final dart leg.
This creates a dart.

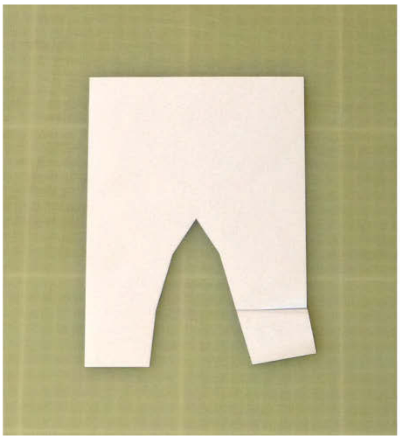
Figure 2: Convex darts can be deconstructed into a series of darts.

A convex dart creates a series of five darts.

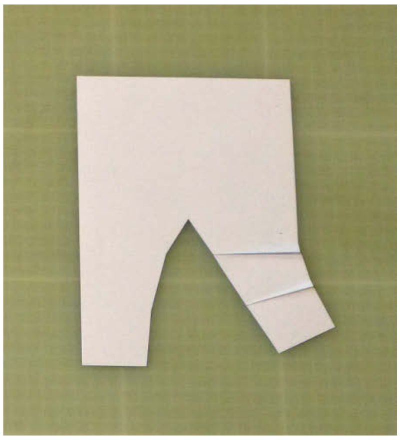
Set 2: Concave



Model 7:
Concave dart flat pattern.
The curved dart is divided into
a series of straight tangent lines.

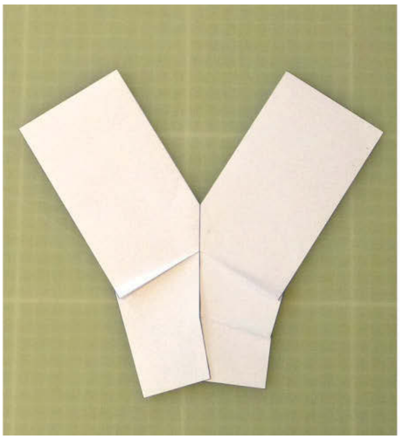


Model 8:
The first apex point is pivoted
using a gusset manipulation.
This creates a gusset.



Model 9:
The next apex point is pivoted
using a gusset manipulation.
This creates a gusset.

Model 10:
The central apex point is pivoted
using a dart manipulation.
This creates a dart.



Model 11:
The next apex point is pivoted
using a gusset manipulation.
This creates a gusset.

Model 12:
The final apex point is pivoted
using a gusset manipulation.
This creates a gusset.

Figure 3: Concave darts can be deconstructed into a dart and a series of gussets.

A convex dart creates a series of four gussets and a dart.

Conclusion

This experiment demonstrates that complex darts can be broken down into a series of darts and gussets. A convex dart can be broken down into a series of darts, while a concave dart creates a gusset as well as several darts. It is instructive to note that these curved darts can be deconstructed into a series of darts and gussets.

Experiment 11: Concave and Convex Gussets

Rationale

This experiment takes patterns that have curved gussets and analyse their geometric properties by deconstructing them into a series of simpler darts and gussets. It analyses patterns with concave and convex shaped gussets to identify their apex points, remembering that each apex point has a dart or a gusset. Using this process a patternmaker can identify the geometric properties of any curved gusset.

Hypothesis

The research anticipates that patterns with convex and concave gussets should be open to deconstruction into a series of smaller darts and gussets.

Experimental Design

Through two sets of experiments it tests the properties of a concave and convex gusset. It deconstructs curved patterns into smaller pieces so that they are open to dart and gusset manipulation. The aim of the process is to identify every single apex point as a dart or a gusset. If the apex is a dart, it can be cut open and flattened in order to observe the dart angle. If it is a gusset, the gusset can be pinched out to measure the size of the gusset angle created.

Procedure

Set 1: Convex gussets

This experiment manipulates a rectangular pattern with a convex gusset inserted into it (see figure 1). A line is cut from the top edge of the pattern and has a distance the same length as the edge of the convex gusset. The edges of the convex gusset have been deconstructed into three straight lines which make the patterns easier to manipulate. The convex gusset is then inserted using tape. The original paper model is printed from a digital file on 80 gsm paper.

Model 1: Create a rectangular pattern with a convex gusset inserted into the top of the pattern.

Model 2: Use gusset manipulation to pivot the apex on the top left of the pattern so that the apex point can be flattened.

Model 3: Use gusset manipulation to pivot the apex on the middle left of the pattern so that the apex point can be flattened.

Model 4: Use gusset manipulation to pivot the apex on the apex on the bottom of the pattern so that the apex point can be flattened.

Model 5: Use gusset manipulation to pivot the apex on the apex on the middle right of the pattern so that the apex point can be flattened.

Model 6: Use gusset manipulation to pivot the apex on the apex on the top right of the pattern so that the apex point can be flattened.

This process flattens the entire pattern into a series of darts and gussets. Analyse the gussets created by this pattern.

Set 2: Concave gussets

This experiment manipulates a rectangular pattern with a concave gusset inserted into it (see figure 1). A line is cut from the top edge of the pattern and has a distance the same length as the edge of the concave gusset. The edges of the concave gusset have been deconstructed into three straight lines which make the patterns easier to manipulate. The concave gusset is then inserted using tape. The original paper model is printed from a digital file on 80 gsm paper.

Model 7: Create a rectangular pattern with a convex gusset inserted into the top of the pattern.

Model 8: Use gusset manipulation to pivot the apex at the centre of the pattern and create a gusset at the bottom of the pattern.

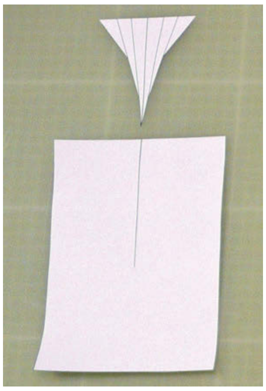
Model 9: Cut a line from the left side of the pattern to the middle left apex point. Use dart manipulation to pivot the apex to flatten the apex.

Model 10: Cut a line from the left side of the pattern to the top left apex point. Use dart manipulation to pivot the apex to flatten the apex.

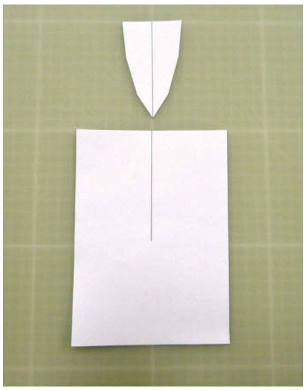
Model 11: Cut a line from the right side of the pattern to the middle right apex point. Use dart manipulation to pivot the apex to flatten the apex.

Model 12: Cut a line from the right side of the pattern to the top right apex point. Use dart manipulation to pivot the apex to flatten the apex.

This process flattens the entire pattern into a series of darts and gussets. Analyse the gussets created by this pattern.



Convex gusset flat pattern.



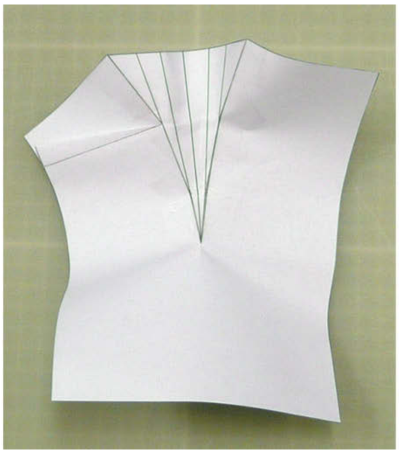
Concave gusset flat pattern.

Figure 1: Convex and concave gussets.

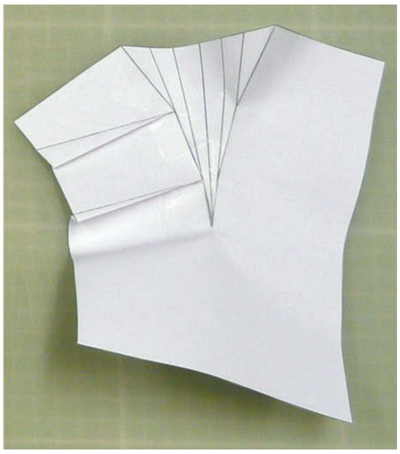
Results

Set 1: Convex gussets

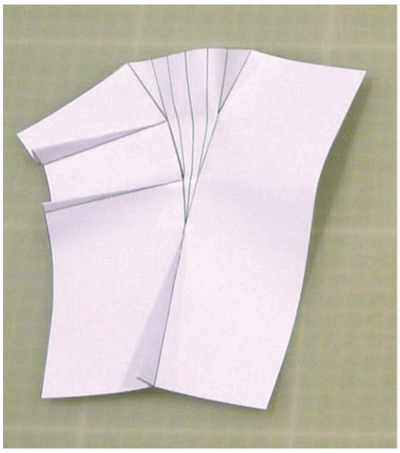
Convex gusset in 3D.



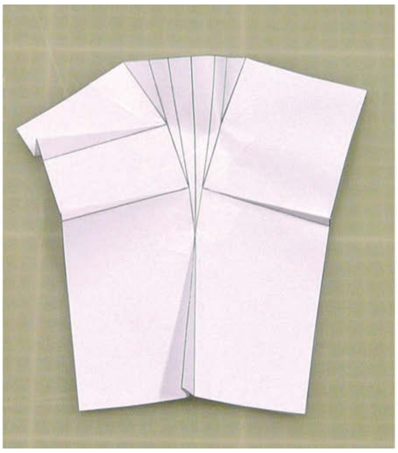
A gusset is created at the top left apex.



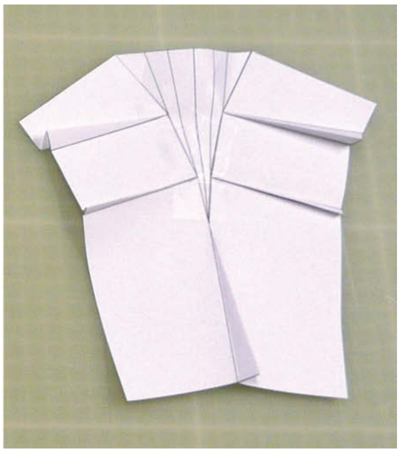
A gusset is created at the middle left apex.



A gusset is created at the central apex.



A gusset is created at the middle right apex.



A gusset is created at the top right apex.

Figure 2: Convex gussets deconstructed into a series of gussets.

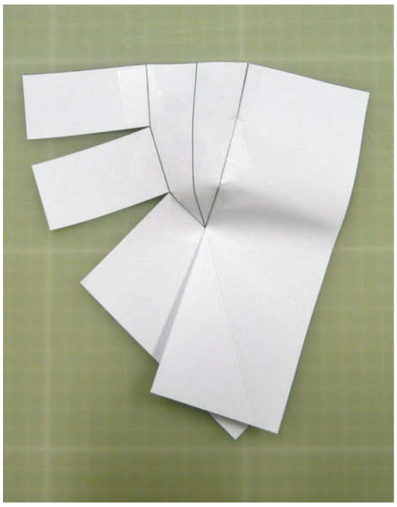
Convex gussets create a series of five gussets.

Set 2: Concave gussets

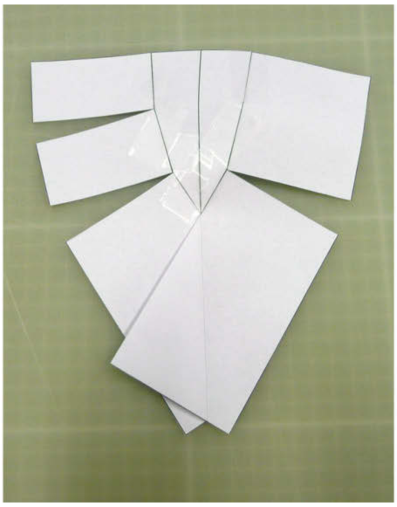
Convex gusset in 3D.

A gusset is taken out of the central apex.

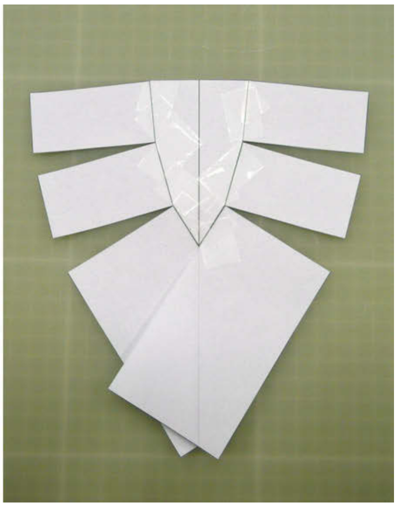
A dart cut from the middle left apex.



A dart cut from the top left apex.



A dart cut from the middle right apex.



A dart cut from the top right apex.

Figure 3: Concave gussets deconstructed into a series of darts and gussets.

Concave gussets create a series of four darts and a gusset.

Conclusion

This experiment demonstrates that a gusset with a complex shape can be deconstructed into a series of darts and gussets. A convex gusset consists of a series of gussets. A concave gusset creates one large gusset and a series of smaller darts.

Experiment 12: Designing on Complex Darts

Rationale

This experiment manipulates the style lines on complex darts while maintaining the geometric shape of the original garment. This technique requires the patternmaker to identify the apex points of a pattern and then draw style lines between the apexes. This allows a designer to express their creativity while still maintaining the fit of the original garment.

Hypothesis

The research anticipates that by using dart and gusset manipulation it should be possible to design a style line on a complex curved pattern that maintains the geometric form of the original pattern.

Experimental Design

The experiment takes a curved convex dart pattern and designs a new style line on the pattern that maintains geometric equivalence with the original pattern. Using the principles of dart and gusset manipulation it can draw style lines of any shape as long as they pass through the apex points of a pattern. It then tests this principle on curved darts and gusset patterns.

Procedure

The experiment demonstrates how to design style lines on curved patterns that maintain geometric equivalence with the original pattern. The apex points of a dart are first identified and then a style line is drawn between these apex points to create a new pattern. The patterns are then cut down the new style line to create a new pattern. It then tests this principle on a complex dart and a complex gusset.

Set 1: Designing on complex darts

Create identical copies of a rectangular pattern with a convex dart. To ensure accuracy, print these patterns from the same digital file on 80 gsm paper.

Model 1: Construct the pattern in 3D using tape.

Model 2: Leave as a flat pattern.

Model 3: Construct the pattern in 3D using tape. Identify the apex points of the pattern.

Model 4: Identify the apex point on the flat pattern.

Model 5: Construct the pattern in 3D using tape. Starting from the bottom edge of the pattern draw a style line which passes through each of the apex points.

Model 6: Recreate the last model. Flatten the pattern in order to observe the style line on a flat pattern.

Model 7: Recreate model 5 and cut down the style line of the pattern to create the new pattern. Re-assemble this pattern to create the new pattern in 3D.

Model 8: Recreate the last model and flatten the pattern in order to observe the new pattern as a flat pattern.

Set 2: Designing on complex gussets

This experiment works with a concave dart inserted into a rectangular pattern. Create identical copies of this pattern. To ensure accuracy print these patterns from the same digital file on 80 gsm paper.

Model 9: Construct the pattern in 3D using tape.

Model 10: Leave as a flat pattern.

Model 11: Construct the pattern in 3D using tape. Identify the apex points of the pattern.

Model 12: Identify the apex points on the flat pattern.

Model 13: Construct the pattern in 3D using tape. Starting at the top edge of the pattern draw a style line which passes through each of the apex points.

Model 14: Re-create the last model. Cut the concave gusset out of the pattern and flatten the pattern. Observe the location of the style lines.

Model 15: Re-create model 13 and cut down the style line of the pattern to create the new pattern. Re-assemble this pattern to create the new pattern in 3D.

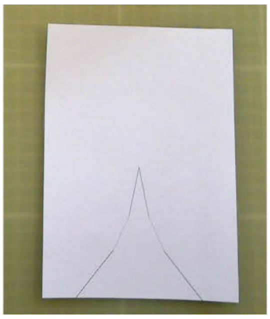
Model 16: Recreate the last model. Cut down the style line and flatten the pattern as a new flat pattern.

Results

Set 1: Designing on a complex dart

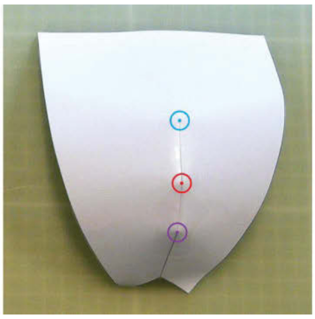
Model 1:

Convex dart in 3D.



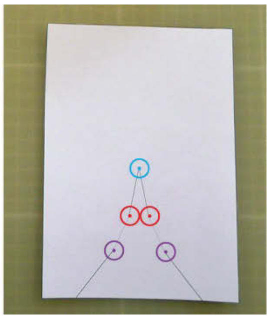
Model 2:

Convex dart flat.



Model 3:

Identify apexes.

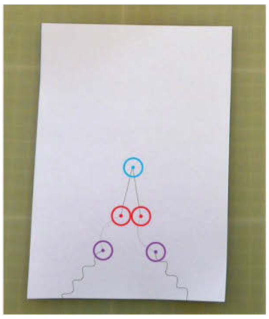


Model 4:

Identify apexes.

Model 5:

Design a line between the apex points.

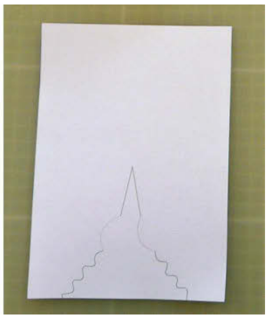


Model 6:

Cut the 3D pattern down the design line to create a flat pattern.

Model 7:

Constructing this new pattern in 3D creates one with the same 3D shape as the original.



Model 8:

Final pattern flat.

Figure 1: Designing on complex darts.

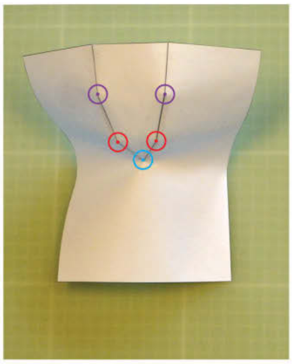
Set 2: Designing on a complex gusset

Model 9:

Convex gusset in 3D.

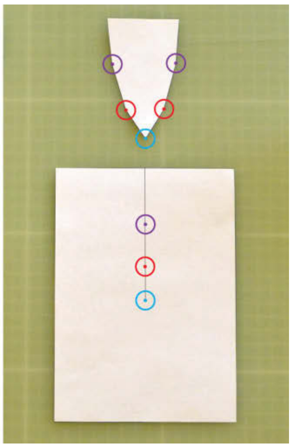
Model 10:

Convex gusset flat.



Model 11:

Identify apexes.

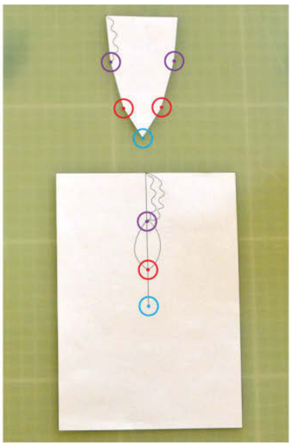


Model 12:

Identify apexes.

Model 13:

Draw a line between the apex.



Model 14:

Draw a line between the apex.

Model 15:

Final Pattern.

Model 16:

Final pattern.

Figure 2: Designing on complex gussets.

Conclusion

This experiment shows that by using a combination of dart and gusset manipulation, it is possible to design a style line on a complex-shaped pattern while maintaining the geometric equivalence of the original form.

4. Contour Manipulation

Experiment 13: **Contour manipulation, part 1**

Experiment 14: **Contour manipulation, part 2**

Experiment 15: **Designing on contours**

Aim

These three experiments explore "contour manipulation" a process that manipulates the style lines of a curved contour while maintaining the original pattern shape. Existing contour tailoring techniques require the patternmaker's expertise to alter the pattern to fit the body, often demanding an iterative process of trial-and-error fittings. There is no equivalent technique for contours that maintains geometric accuracy with the same precision as dart manipulation. Contour manipulation is a way of dividing a curved pattern into a series of apexes and tangent points. The patterns can be manipulated using a combination of dart and gusset manipulation, and a contour pattern can be deconstructed into a series of apex points that have darts and gussets. Hereby, the research observes the structure and function of a curve. In sum, contour manipulation allows style lines of different shapes to be drawn on the garment while maintaining its three-dimensional form.

Method

The first experiment shows how a contour can be used to deconstruct convex and concave shapes, which are then deconstructed into a series of darts and gussets. The contours are stylised into a series of straight edges to make them easier to manipulate. The experiment also looks at examples of contours with smoother curves that create more apex points. The second experiment explores different combinations of convex and concave contours that can be joined together. It joins together contours of different sizes, seeking to illustrate how a contour of any shape or size can be analysed using contour manipulation. The final experiment in the group demonstrates how to design on a contour while still maintaining the garment's original three-dimensional form.

Analysis

This experimental series demonstrates how any contour can be analysed by deconstructing it into a series of apex points with darts and gussets. The first experiment reveals that joining two convex contours together creates a series of apex points with darts, and that a combination of two concave darts creates a series of gussets. It is observed that when joining contours, the greater the curvature of the contour, the more apex points are created. In the second experiment contours of different shapes and sizes are joined. When joining a convex contour to a concave one, the convex side of the contour becomes a series of darts and the concave side becomes a series of gussets. Contours of different sizes produce different numbers of apex points depending on their curvature, so that the contours can be used to analyse any shape of curve encountered in conventional patternmaking techniques. The final experiment of the group shows how a style line that passes through the apex points of a contoured seam line maintains the same three-dimensional shape as the original garment.

Experiment 13: Contour Manipulation Part 1

Rationale

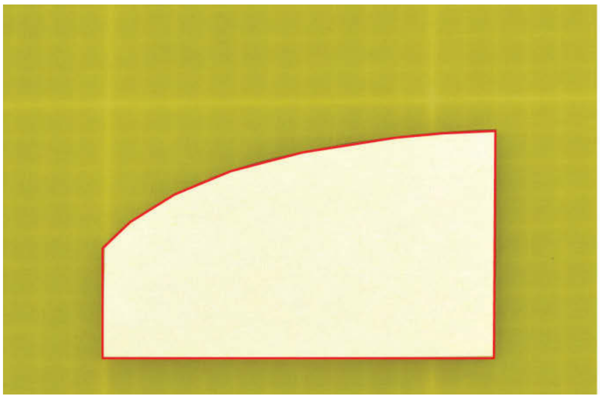
This experiment takes curved patterns and uses a combination of dart and gusset manipulation to analyse their structure. In patternmaking, darts can be manipulated with precision, yet when worked with curved or "contour" techniques, they are less accurate and often require trial-and-error fittings. This experiment tests a technique known as "contour manipulation", which takes complex curves and deconstructs them into a series of apex points that have darts or gussets. This allows patternmakers to understand the structure and function of each part of a complex curve. It also allows them to draw style lines between the apex points in order to design patterns without a loss of geometric accuracy. Contour manipulation is a combination of dart and gusset manipulation, and it should allow all curves to be manipulated with the precision of dart or gusset manipulation, thus increasing the accuracy of contour patternmaking.

Hypothesis

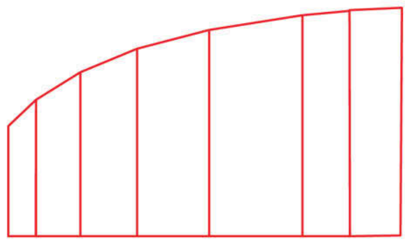
The research anticipates that contoured pattern pieces can be deconstructed into a series of darts and gussets.

Experimental Design

The experiment tests the technique of contour manipulation, which is able to take any curved pattern and deconstruct it into a series of apex points with darts or gussets. The curved lines of a pattern are deconstructed into a series of straight lines and apex points (see figure 1). These patterns are all manipulated using a combination of dart or gusset manipulation. This flattens a curved pattern so that it can be deconstructed into a series of darts, gussets and apex points (see figure 2). It tests both concave and convex curves (see figure 3), as well as curves of different levels of curvature.

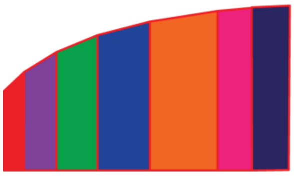


A convex curve.

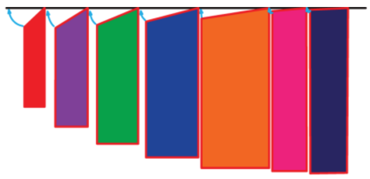


A convex curve deconstructed into straight lines.

Figure 1: Deconstructing a curve into a series of straight lines for contour manipulation.



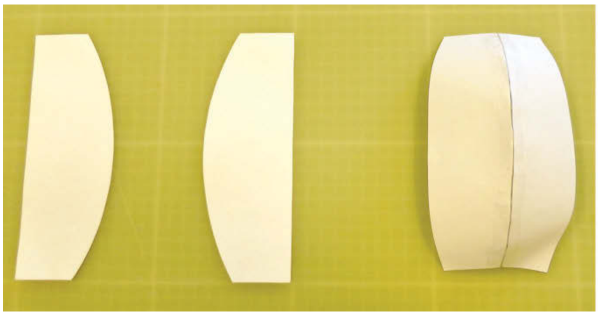
The complex curve is deconstructed into a series of straight lines.



Different parts of the curve are manipulated into a straight line.

The curve is manipulated into a straight line and a series of darts .

Figure 2: The process of manipulating a curved contour into a straight line.



Convex patterns create a spherical-shaped pattern.

Concave patterns create a hyperbolic-shaped pattern.

Figure 3: Spherical and hyperbolic shaped surfaces created by contoured patterns.

Procedure

The experiment consists of four sets of iterations. It will test two sets each of convex and concave contours. The first two sets of contour patterns are less curved and have fewer apex points. The next two sets of patterns have greater curvature and will have more apex points. The experiment takes contours of different sizes and identifies their apex points. The patterns are then manipulated until the seam at the centre of the pattern is straightened and each apex point has a dart or a gusset.

Set 1: Convex contour

Create a convex contoured pattern where each of the edges of the pattern is a straight line. Create multiple identical copies of this pattern. Print them from the same digital file on 80 gsm paper. This experiment records each step of a manipulation as a sequence of physical models. For each pattern re-create a copy of the last model and apply the next transformation to the pattern.

Model 1: Leave as a flat pattern.

Model 2: Identify the apex points of the pattern and draw straight lines from the apex line to the edges of the pattern. These straight lines will be used as a template when pivoting the apex points in the pattern.

Model 3: Starting on the pattern piece on the right side, cut a straight line from the edge of the pattern to the apex on the bottom right of the pattern. Pivot this pattern piece so that it is aligned with the straight edge next to it.

Model 4: Cut a straight line from the middle apex on the right to the edge of the pattern. Pivot the pattern piece to align with the straight edge next to it.

Model 5: Cut a straight line from the next apex in the middle right side of the pattern to the edge of the pattern. Pivot the pattern piece to align with the straight edge next to it.

Model 6: Cut a straight line from the top right apex on the right to the edge of the pattern. Pivot the pattern piece to align with the straight edge next to it. This should make the curve a straight line.

Model 7: Apply this procedure to the other side of the pattern. Cut a straight line from the apex on the bottom left to the edge of the pattern. Pivot the pattern piece to align with the straight edge next to it. Then attach the pattern on the left to the pattern on the right.

Model 8: Cut a straight line from the apex second to the bottom of the pattern to the left to the edge of the pattern. Pivot the pattern piece to align with the straight edge next to it.

Model 9: Cut a straight line from the next apex in the middle of the pattern to the left to the edge of the pattern. Pivot the pattern piece to align with the straight edge next to it.

Model 10: Cut a straight line from the top apex on the left to the edge of the pattern. Pivot the pattern piece to align with the straight edge next to it. This should turn the convex contour into a straight line.

Set 2: Concave contour

Create a convex contoured pattern where each of the edges of the pattern is a straight line.

Model 11: Leave as a flat pattern.

Model 12: Identify the apex points of the pattern and draw straight lines from the apex line to the edges of the pattern. These straight lines will be used as a template when pivoting the apex points in the pattern.

Model 13: On the right pattern piece, start on the bottom apex. Use gusset manipulation to pinch out a gusset and pivot the pattern so that the edge is aligned to the straight edge next to it.

Model 14: Move to the next apex point on the pattern and pinch out a gusset to straighten the curve.

Model 15: Move to the next apex point on the pattern and pinch out a gusset to straighten the curve.

Model 16: Move to the next apex point on the pattern and pinch out a gusset to straighten the curve. This should straighten the entire curve into a straight line.

Model 17: Start manipulating the left side of the contour pattern. At the bottom apex use gusset manipulation to pinch out a gusset to straighten the curve. Then attach the two patterns together so that the pattern joins on a straight line that runs down the centre of the garment.

Model 18: On the apex second to the bottom use gusset manipulation to pivot the curve so that it becomes a straight line.

Model 19: Move to the apex second from the top and pinch out an apex so that the curve forms a straight line.

Model 20: Move to the top apex and pinch out an apex so that the curve forms a straight line. The curved contour pattern should now be a straight line and reveal the apex points with a series of gussets.

Set 3: Detailed convex contour

Model 21: Leave as a flat pattern.

Model 22: Leave as a flat pattern. Identify the apex point on the pattern and draw straight lines from the apex points to the edge of the pattern.

Model 23: Starting at an apex in the middle on the right side of a pattern, cut a line from the apex to the edge of the pattern and then pivot the pattern so the edge of the contour curve forms a straight line.

Model 24: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 25: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 26: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 27: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 28: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 29: Starting at the apex point manipulated in model 23, move up one apex. Cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 30: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 31: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 32: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 33: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 34: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it. The whole left edge of the curved pattern should now be straightened.

Model 35: This process is now going to be applied to the left side of the garment. Move to the apex in the middle of the pattern. Cut a line from the apex to the edge of the pattern and then pivot the pattern so that it aligns with the edge next to it.

Model 36: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 37: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 38: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 39: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 40: Move down to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 41: Move to the apex point in the centre of the pattern and move up one apex. Cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 42: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 43: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 44: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 45: Move up to the next apex point, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it. The entire contour pattern should now be straightened and turned into a series of apex points that create darts.

Set 4: Detailed concave contour

In this pattern there are so many gussets that it is difficult to fit them all in and flatten the pattern. Instead, a line will be cut down the pattern so that it can be seen how much the patterns overlap like a gusset.

Model 46: Leave as a flat pattern. Identify the apex point on the pattern and draw straight lines from the apex points to the edge of the pattern.

Model 47: Align to bottom edge of the right pattern on a straight line running down the centre of the pattern.

Model 48: Then cut down the straight line on the bottom right of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 49: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 50: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 51: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 52: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 53: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 54: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 55: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 56: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 57: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 58: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it. This procedure has straightened the entire curved edge of the pattern into a straight line.

Model 59: Align the bottom edge of the left pattern to the straight edge of the right pattern and attach the two patterns.

Model 60: Starting at the bottom left apex, cut a line from the apex to the edge of the pattern and pivot the pattern so that it aligns with the edge next to it.

Model 61: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 62: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 63: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 64: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 65: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 66: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 67: Move up to the next apex point and pivot the pattern so that it aligns with the edge next to it.

Model 68: At the top apex point, pivot the pattern so that it aligns with the edge next to it. The entire contour pattern should now be straightened and turned into a series of apex points that overlap like gussets.

Results

Set 1: Convex contour

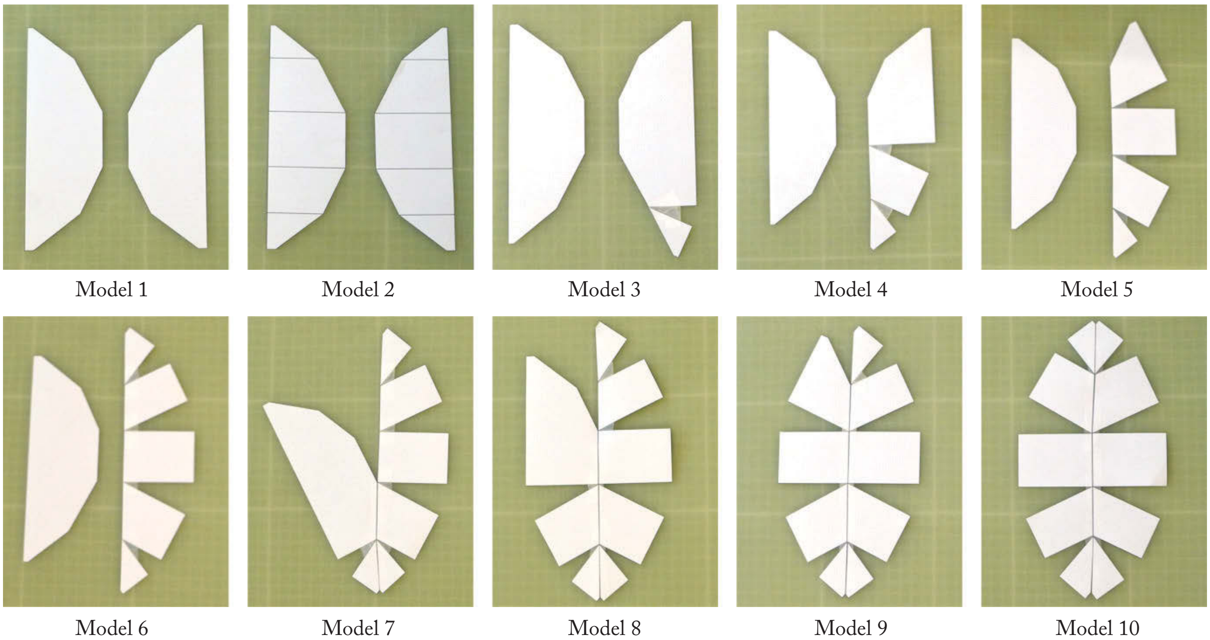


Figure 4: Two convex curves joined together. When manipulated onto a straight line, a series of darts is created.

Set 2: Concave contour

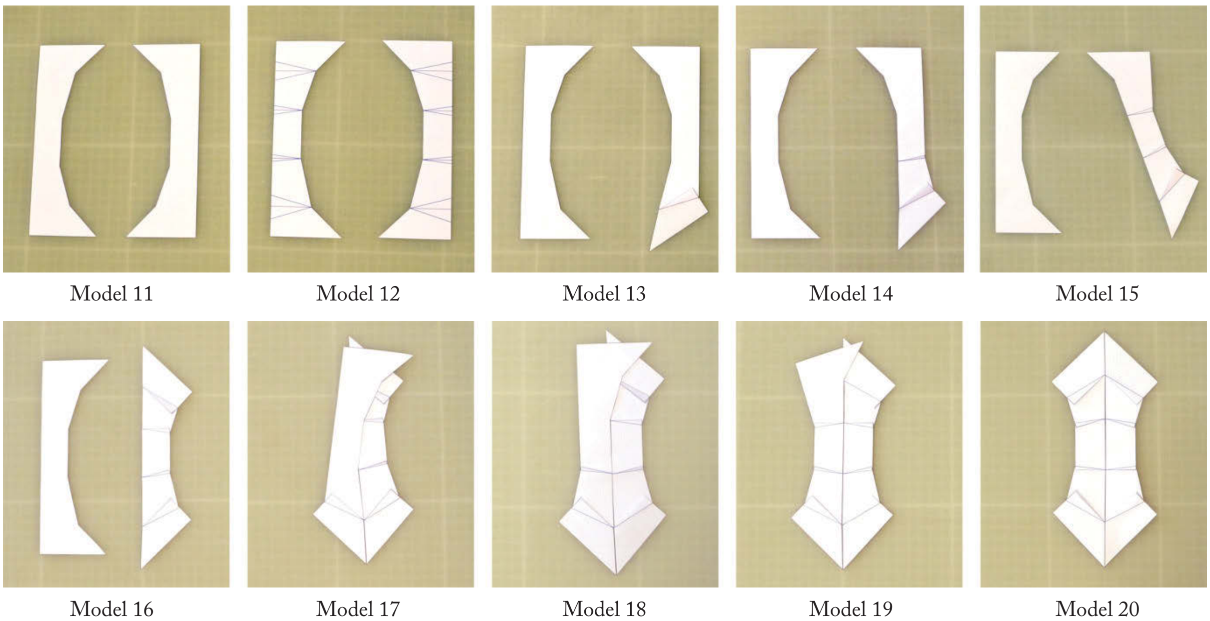
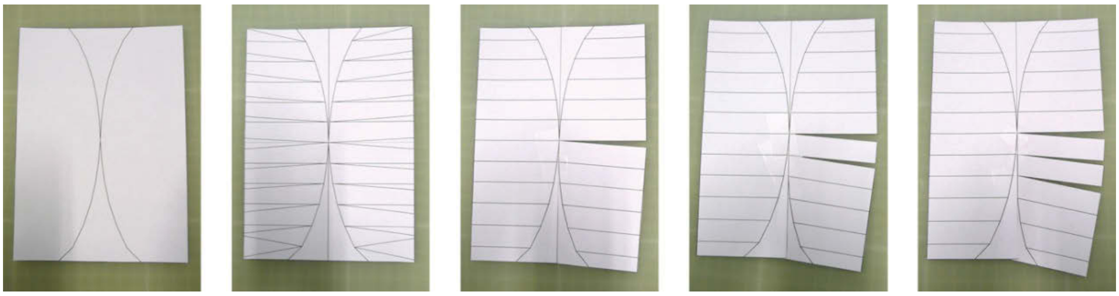
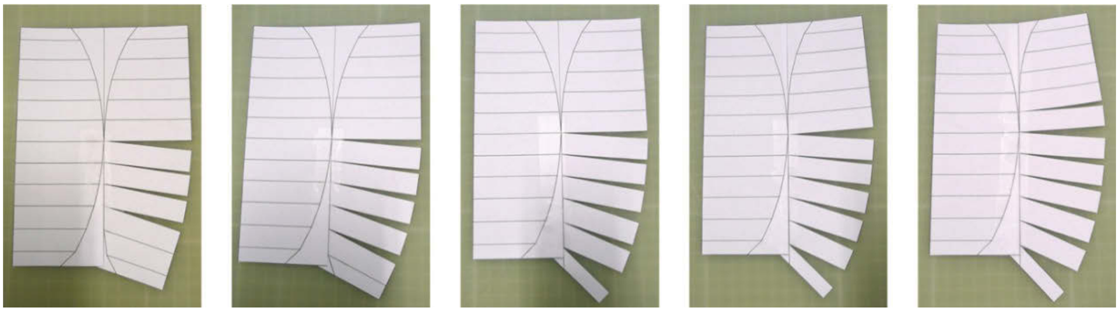


Figure 5: Two concave curves joined together. When manipulated onto a straight line, a series of gussets is created.

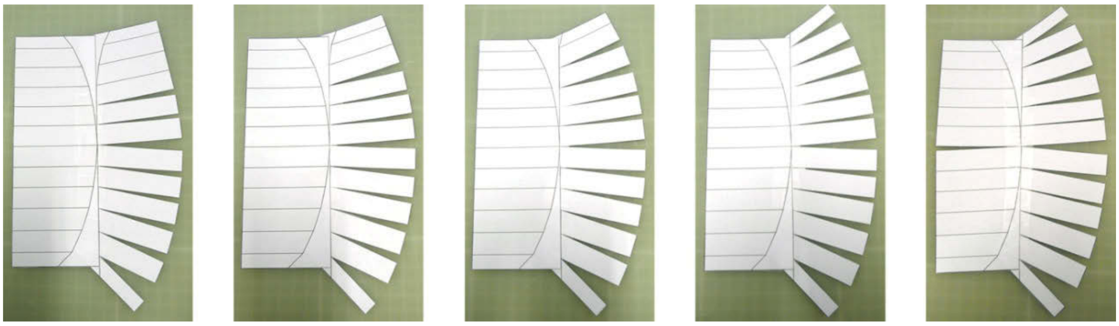
Set 3: Detailed convex contour



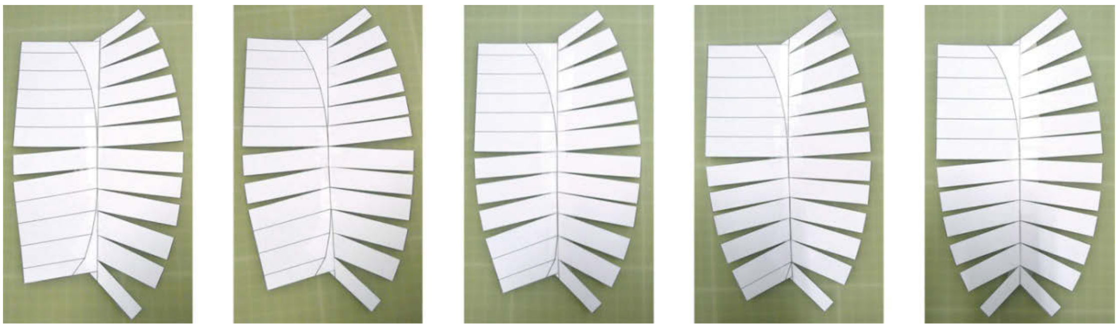
Model 21 Model 22 Model 23 Model 24 Model 25



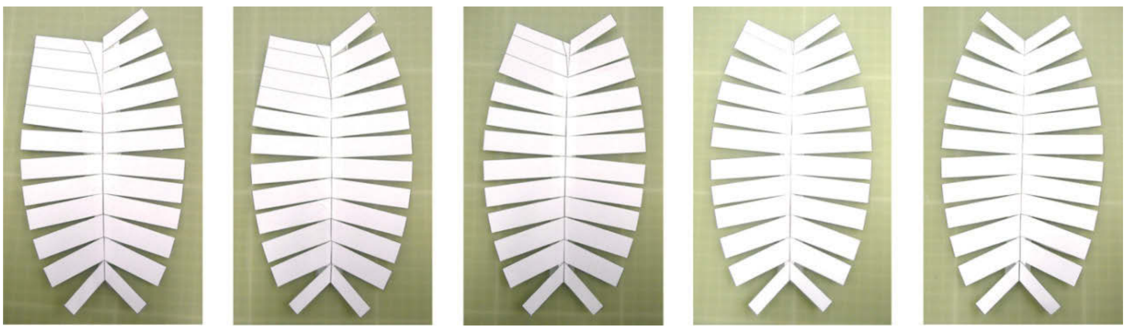
Model 26 Model 27 Model 28 Model 29 Model 30



Model 31 Model 32 Model 33 Model 34 Model 35



Model 36 Model 37 Model 38 Model 39 Model 40



Model 41 Model 42 Model 43 Model 44 Model 45

Figure 6: A convex contour manipulated into a straight line. The pattern creates a series of darts.

Set 4: Detailed concave contour

Model 46 Model 47 Model 48 Model 49 Model 50
Model 51 Model 52 Model 53 Model 54 Model 55
Model 56 Model 57 Model 58 Model 59 Model 60
Model 61 Model 62 Model 63 Model 64 Model 65
Model 66 Model 67 Model 68

Figure 7: A concave contour manipulated into a straight line. The pattern overlaps creating a series of gussets.

Conclusion

The experiment demonstrates that by using contour manipulation, convex curves can be deconstructed into a series of darts, while concave darts can be deconstructed into a series of gussets. The smoother the curve, the greater the amount of apex points there are.

Experiment 14: Contour Manipulation Part 2

Rationale

This experiment uses contour manipulation to analyse concave and convex patterns of different shapes and sizes when they are joined together. Using contour manipulation, it deconstructs curved contour patterns into a series of apex points that have darts and gussets.

Hypothesis

The research anticipates that combinations of concave and convex patterns will create different configurations of patterns.

Experimental Design

The experiment is designed to use contour manipulation to reveal the structure of different shaped curves as they join together. Using contour manipulation the curved patterns are deconstructed into a series of straight lines and their patterns are pivoted to create a straight line that runs down the centre of the pattern. This reveals the contour's apex points which are a dart or gusset. The first iteration joins together concave and convex curves of a similar size, and the second joins two convex curves of different sizes. The third iteration joins together two concave curves of different sizes, while the fourth joins a concave curve and convex curve of different sizes. The fifth iteration joins a concave and convex curve of similar sizes.

Procedure

The experiment consists of five sets of iterations. When making models, recreate the previous model, then apply the next set of instructions to it.

Set 1: Concave and convex curves of a similar size

Create concave and convex contoured patterns where each of the edges of the pattern is a straight line. Create multiple identical copies of this pattern. Print them from the same digital file on 80 gsm paper.

Model 1: Leave as a flat pattern. Identify the apex points of the pattern and draw straight lines from the apex line to the edge of the pattern.

Model 2: Attach the centre parts of the pattern pieces.

Model 3: Starting on top apex point on the left pattern piece, pinch out a gusset so that the curved edge aligns with the edge next to it.

Model 4: Move down to the next apex and pinch out a gusset so that the edge becomes a straight line.

Model 5: Move down to the next apex and pinch out a gusset so that the edge aligns with the edge next to it.

Model 6: Move down to the next apex and pinch out a gusset so that the edge aligns with the edge next to it. The entire left side of the pattern should now be a straight line.

Model 7: The same procedure will be applied to the other side of the pattern. Starting at the top right apex point cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 8: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 9: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 10: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it. The curved seam line of the original pattern should now be deconstructed into a series of darts and gussets on a straight line.

Set 2: Two convex curves of different sizes

Create two convex contoured patterns of different sizes where each of the edges of the pattern is a straight line. Create multiple identical copies of this pattern. Print them from the same digital file on 80 gsm paper.

Model 11: Leave as a flat pattern.

Model 12: Attach the centre parts of the pattern pieces.

Model 13: Identify the apex points of the pattern and draw straight lines from the apex line to the edges of the pattern. Starting on top left apex point cut a straight line from apex to the edge of the pattern. Pivot this pattern piece so that its edge is aligned with the edge next to it.

Model 14: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 15: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 16: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it. The entire left side of the pattern should now be a straight edge.

Model 17: Apply this procedure to the other side of the pattern. Starting on top right apex point cut a straight line from apex to the edge of the pattern. Pivot this pattern piece so that its edge is aligned with the edge next to it.

Model 18: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 19: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 20: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it. The curved lines should now be straightened and the pattern deconstructed into a series of darts.

Set 3: Two concave curves of different sizes

Create two concave patterns of different sizes where each of the edges of the pattern is a straight line. Create multiple identical copies of this pattern. Print them from the same digital file on 80 gsm paper.

Model 21: Leave as a flat pattern.

Model 22: Identify the apex points of the pattern and draw straight lines from the apex line to the edges of the pattern. These straight lines will be used as a template when pivoting the apex points in the pattern.

Model 23: Attach the two base edges of the patterns together. Starting at the bottom right pattern piece pinch out a gusset so that the pattern piece aligns with the straight edge next to it.

Model 24: Move up to the next apex point, then pinch out another gusset so that the pattern piece aligns with the straight edge next to it.

Model 25: Move up to the next apex point, then pinch out another gusset so that the pattern piece aligns with the straight edge next to it.

Model 26: Move up to the next apex point, then pinch out another gusset so that the pattern piece aligns with the straight edge next to it. The entire right side of the pattern should now be a straight line.

Model 27: Apply this procedure to the other side of the pattern. Start at the bottom apex point and pinch out a gusset so that the edge of the pattern aligns with the straight edge next to it.

Model 28: Move up to the next apex point, then pinch out another gusset so that the edge of the pattern aligns with the straight edge next to it.

Model 29: Move up to the next apex point, then pinch out another gusset so that the edge of the pattern aligns with the straight edge next to it.

Model 30: Move up to the next apex point, then pinch out another gusset so that the edge of the pattern aligns with the straight edge next to it. The curved lines should now be straightened and the pattern deconstructed into a series of gussets.

Set 4: Concave and convex curves of a different size

Create a concave and a convex contoured pattern of different sizes where each of the edges of the pattern is a straight line. Create multiple identical copies of this pattern. Print them from the same digital file on 80 gsm paper.

Model 31: Leave as a flat pattern.

Model 32: Identify the apex points of the pattern and draw straight lines from the apex to the edges of the pattern.

Model 33: Attach the two middle edges of the patterns together.

Model 34: Starting at the bottom left apex point pinch out a gusset so that the pattern piece aligns with the straight edge next to it.

Model 35: Move up to the next apex point, then pinch out another gusset so that the pattern piece aligns with the straight edge next to it.

Model 36: Move up to the next apex point, then pinch out another gusset so that the pattern piece aligns with the straight edge next to it.

Model 37: Move up to the next apex point, then pinch out another gusset so that the pattern piece aligns with the straight edge next to it. The curved pattern on the left side of the pattern should now be straightened.

Model 38: Apply this procedure to the other side of the pattern. Starting at the bottom left apex point cut a straight line from apex to the edge of the pattern. Then pivot the pattern piece so that it aligns with the straight edge next to it.

Model 39: Move up to the next apex point and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 40: Move up to the next apex point and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 41: Move up to the next apex point and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it. The entire curve should now be a straight line. The pattern is a series of apex points with darts and gussets.

Set 5: Concave and convex curves of a similar size

Create a convex and a concave contoured pattern of similar sizes where each of the edges of the pattern is a straight line. Create multiple identical copies of this pattern. Print them from the same digital file on 80 gsm paper.

Model 42: Leave as a flat pattern.

Model 43: Identify the apex points of the pattern and draw straight lines from the apex line to the edges of the pattern.

Model 44: Move the pieces together to show that they interlock like a jigsaw puzzle.

Model 45: Attach the top two edges of the pattern pieces together. Cut a line from top left apex point to the edge of the pattern. Pivot the pattern so that the pattern overlaps like a gusset and the edge is aligned with the straight edge next to it.

Model 46: Move down to the next apex. Cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 47: Move down to the next apex. Cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it. The entire left side of the pattern should now be a straight line.

Model 48: Apply this procedure to the other side of the pattern. Move to the right apex and cut a line from the apex point to the edge of the pattern. Pivot the pattern to create a dart so that the edge of the pattern piece aligns with the edge next to it.

Model 49: Move down to the next apex. Cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 50: Move down to the next apex. Cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 51: Move down to the next apex. Cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it. The entire pattern should now be deconstructed into a series of apex points with darts and gussets.

Results

Set 1: Concave and convex curves of a similar size

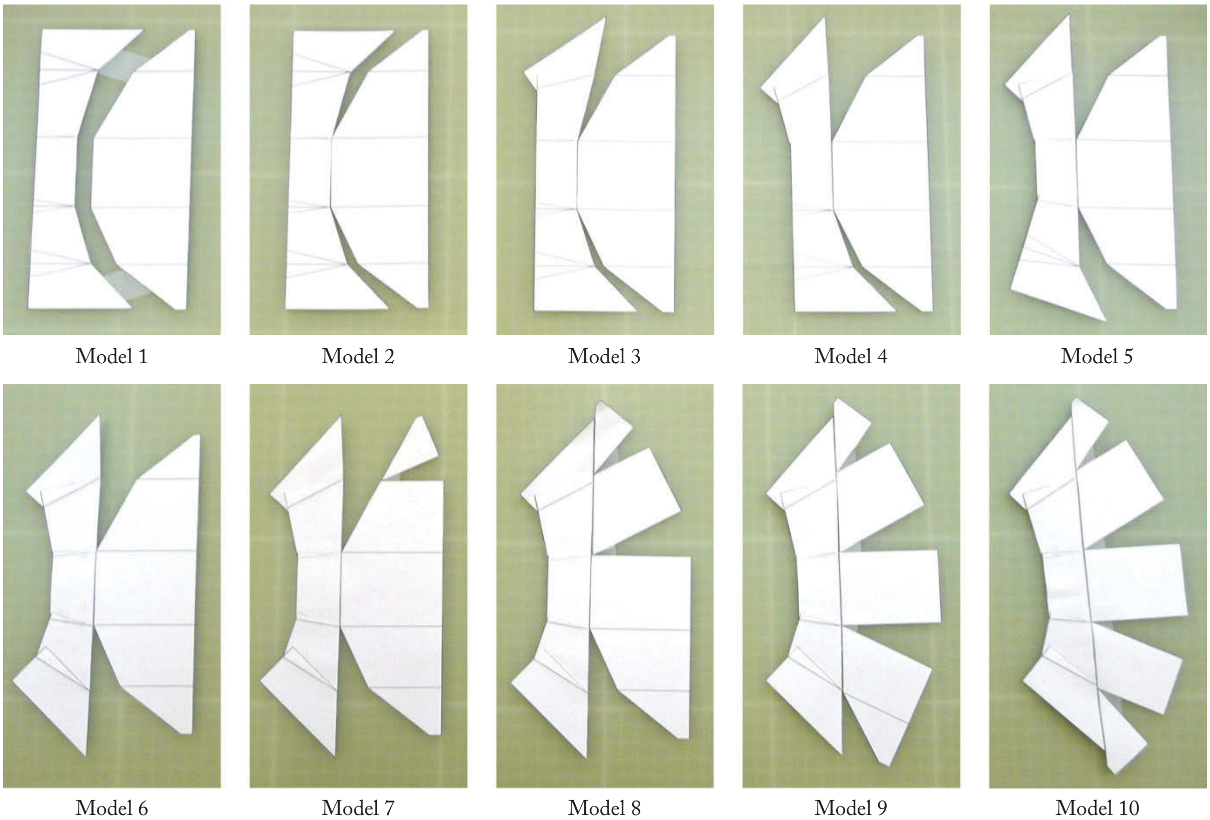


Figure 1: A concave and a convex curve are joined together and deconstructed into a series of darts and gussets.
Concave curves create a series of gussets while convex curves create a series of darts.

Set 2: Two convex curves of different sizes

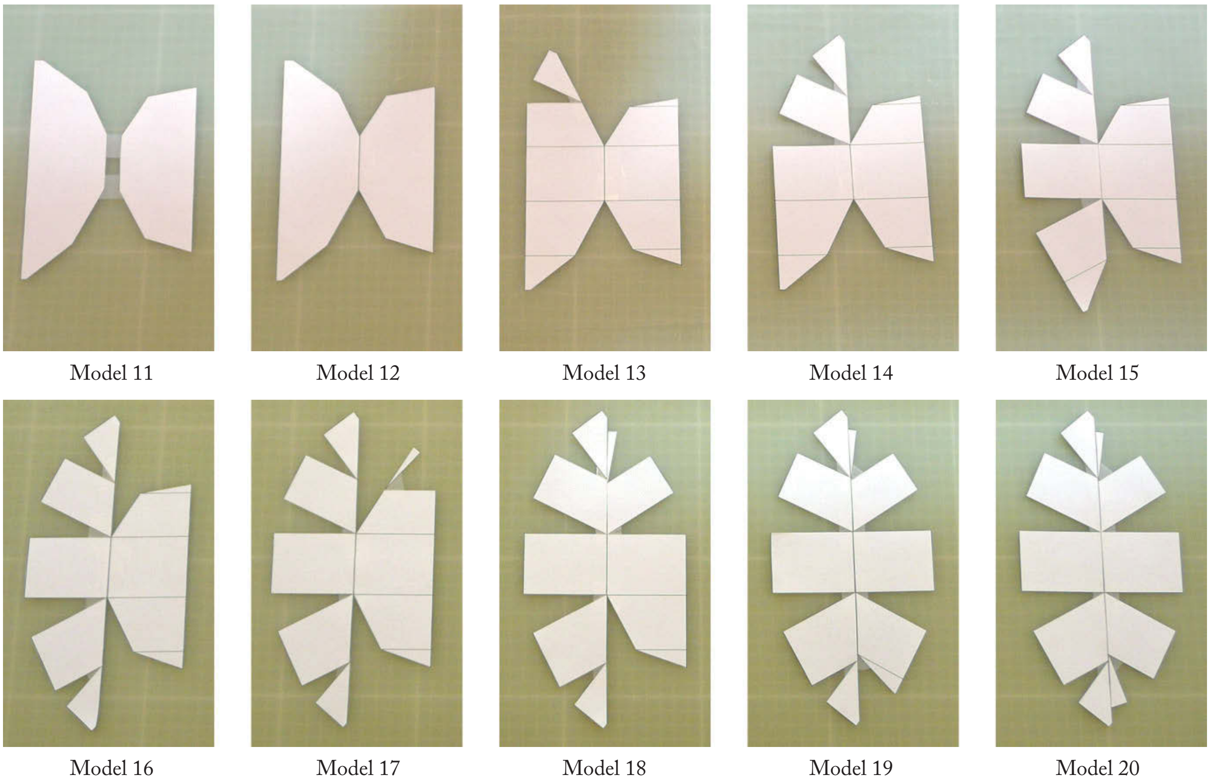


Figure 2: Two convex curves of different sizes together. This creates a series of darts.

Set 3: Two concave curves of different sizes

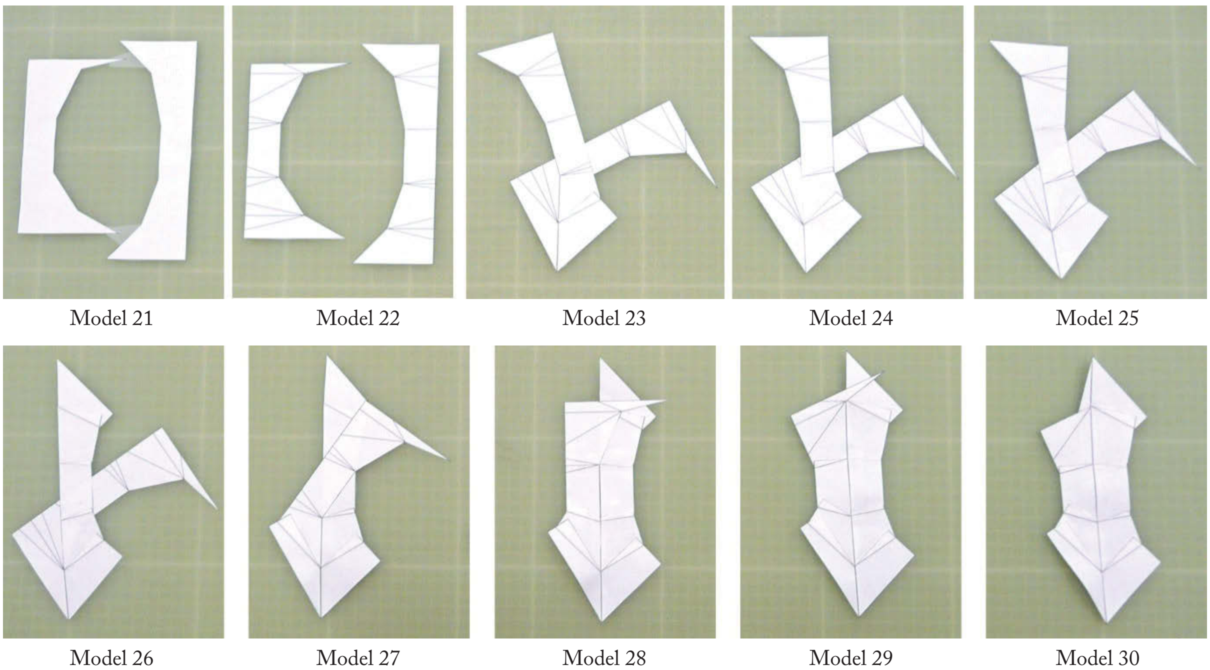
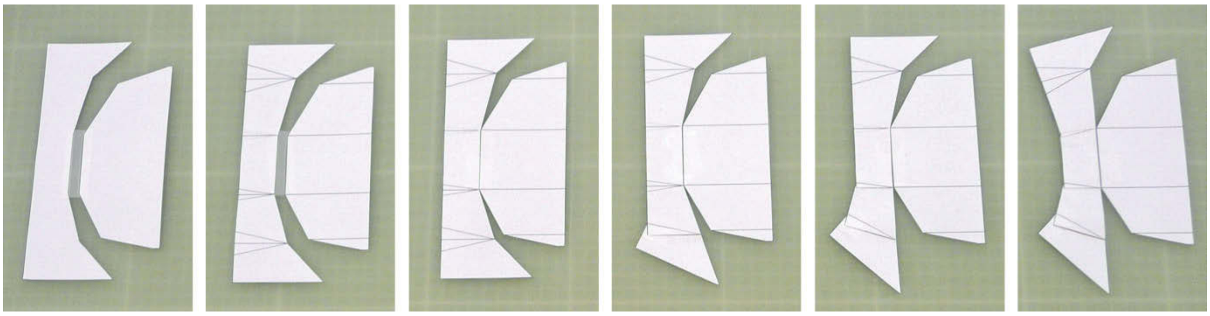
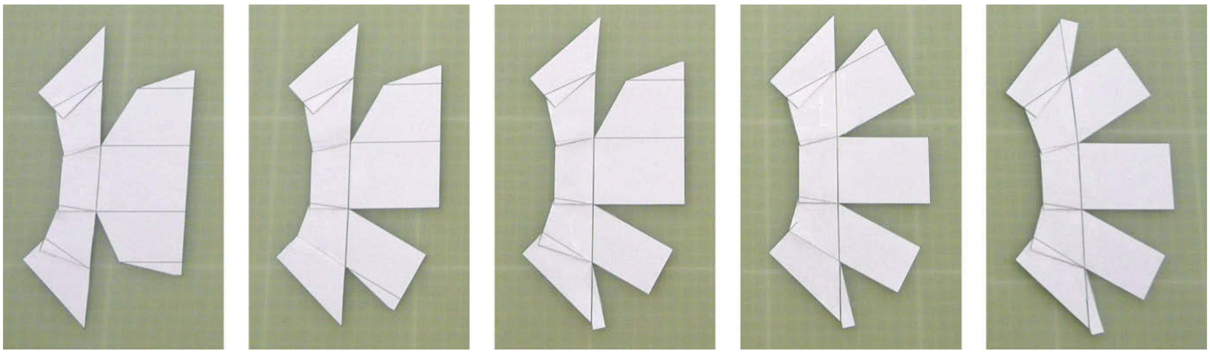


Figure 3: Two concave curves of different sizes joined together. This creates a series of gussets.

Set 4: Concave and convex curves of a different size



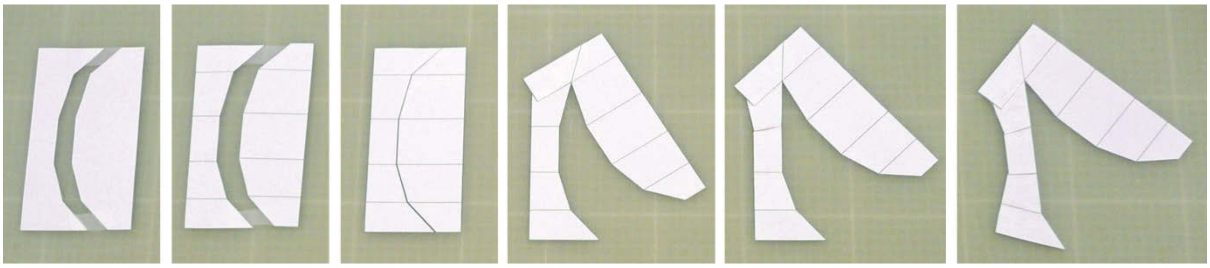
Model 31 Model 32 Model 33 Model 34 Model 35 Model 36



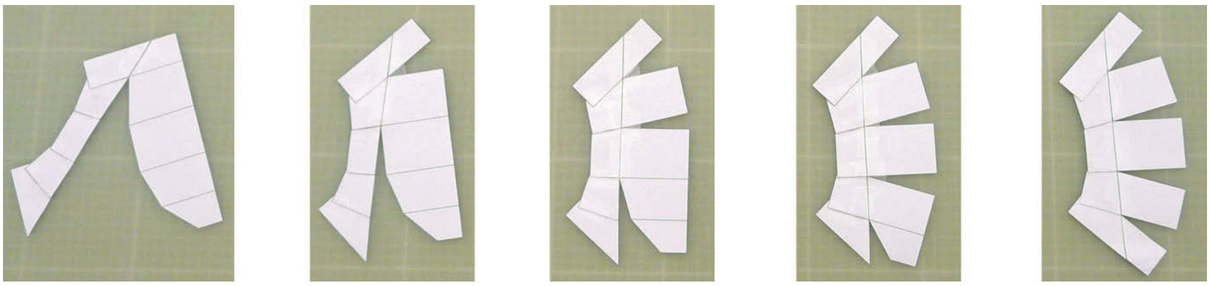
Model 37 Model 38 Model 39 Model 40 Model 41

Figure 4: A concave and a convex curve of different sizes are joined together, deconstructed into a series of darts and gussets.

Set 5: Concave and Convex curves of a similar size



Model 41 Model 42 Model 43 Model 44 Model 45 Model 46



Model 47 Model 48 Model 49 Model 50 Model 51

Figure 5: Drawing a curved line on a piece of paper creates a concave and a convex curve.

They both create a series of darts and gussets, but when joined together the darts and gussets cancel each other out.

Conclusion

The experiment shows that any contoured curve can be deconstructed into a series of apex points that have darts or gussets, allowing designers to manipulate their patterns without losing geometric accuracy.

Experiment 15: Designing on Contours

Rationale

This experiment demonstrates how to use "contour manipulation", a way of moving the location of the style lines while maintaining the same geometric form as the original garment. Identifying the location of the apexes on the pattern allows a patternmaker to manipulate the garment with greater precision.

Hypothesis

The research anticipates that it can design a style line geometrically equivalent to the original pattern, if the style line passes through all the apex points.

Experimental Design

The experiment shows how to use contour manipulation to design style lines of different shapes while retaining the exact shape of the original pattern. It takes two convex curves and identifies all the apex points of the curve. It then constructs the patterns in 3D. Following this, a new style line is drawn from the edge of the pattern, passing through all the apex points. As long as the style line passes through all of them, it is still possible to flatten the pattern. The new pattern is then cut and flattened. The final pattern has a new style line which retains the same three-dimensional form as the original garment.

Procedure

Create a convex contoured pattern where each of the edges of the pattern is a straight line. Then create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. The experiment will show the transformation as a series of paper models. Start each model with a copy of the previous model and then add the additional transformations.

Model 1: Construct the pattern in 3D.

Model 2: Leave as a flat pattern.

Model 3: Construct the pattern in 3D. Identify all the apexes on the pattern and draw a straight line from the apex to the edge of the garment. Draw a new style line from the top edge of the pattern through all the apexes to the bottom of the pattern.

Model 4: Cut this pattern down the centre and flatten the pattern.

Model 5: Re-create the pattern in model 3 and cut through the style line.

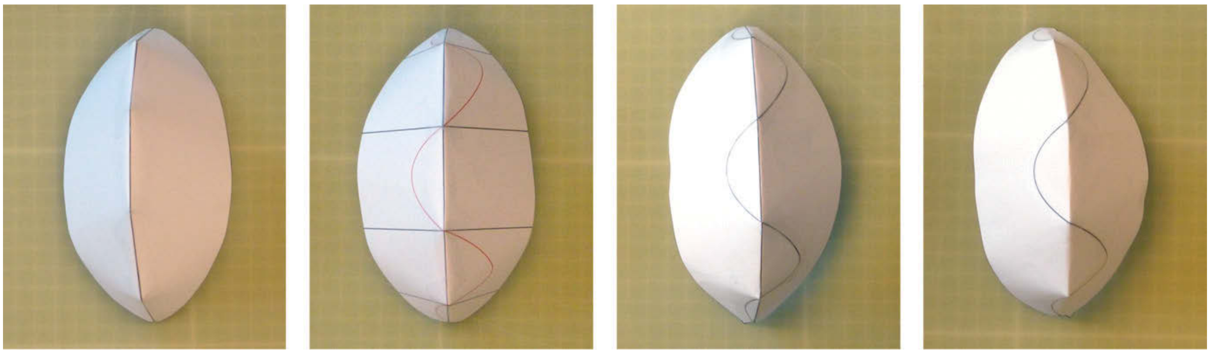
Model 6: Flatten the pattern with the new style line.

Model 7: Trace the pattern in model 6 to create the new pattern. Then construct the pattern in 3D.

Model 8: Cut through the style line to flatten the pattern.

Results

Set 1: Designing on a contour pattern

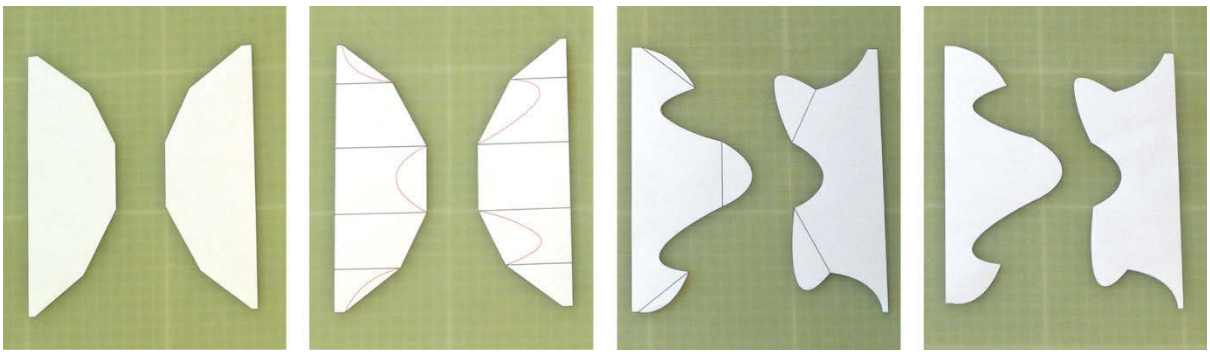


3D Model 1

3D Model 3

3D Model 5

3D Model 7



Flat Model 2: A contoured pattern.

Flat Model 4: Apexes defined. Style line drawn of contour.

Flat Model 6: Pattern reconstructed into a new pattern.

Flat Model 8: The new pattern has geometric equivalence.

Figure 1: Drawing a curved style line on a contoured pattern while maintaining geometric equivalence.

Conclusion

The experiment demonstrates that by applying contour manipulation to a curved pattern, it is possible to create a new style line on the pattern that maintains the same geometric form as the original pattern.

5. Asymmetrical Darts and Gussets

Experiment 16: **Asymmetrical darts**

Experiment 17: **Symmetrical and asymmetrical darts**

Experiment 18: **Asymmetrical gussets**

Experiment 19: **Curved contour lines in contour manipulation**

Aim

This group of experiments explores the properties of asymmetrical darts, namely: darts that have dart legs of different shapes and different numbers of apex points. Symmetrical darts are used much more in patternmaking as they are easier to sew, yet asymmetrical darts offer advantages as they tend to create far more intricate shapes. The experiments use contour manipulation to investigate the properties of asymmetrical darts and gussets, and go so far as to test an alternate version of contour manipulation on asymmetrical darts and gussets.

Method

The first experiment defines the properties of an asymmetrical dart and counts the number of apex points on each dart leg. The second compares the differences between symmetrical and asymmetrical darts. The third experiment uses gusset manipulation to explore the properties of asymmetrical gussets. The final experiment explores an alternative technique for contour manipulation that flattens the contours over a curved line and creates a single dart or gusset at each apex point.

Analysis

Asymmetrical darts and gussets offer different properties to symmetrical gussets. Darts are defined as asymmetrical if their dart legs do not possess rotational or mirror symmetry. Due to the asymmetry of the dart legs they are able to hold more apex points, creating more opportunities to shape the garment. Asymmetrical gussets also have more apex points than symmetrical ones, and have the additional property that they contain more sites for apex points. An asymmetrical dart only has one seam line for creating apex points while an asymmetrical gusset creates two seam lines. This means that asymmetrical gussets contain more sites for apex points. The final item in this experimental group is an alternate method for contour manipulation that creates a contour on a curved line. Usually in this practice both sides of a contour are straightened into a single straight line. This technique only manipulates one side of the pattern, and the apex points lie on a curved line. The advantage is that it takes less time to apply, and each apex has a single dart or gusset.

Experiment 16: Asymmetrical Darts

Rationale

This experiment explores the properties of asymmetrical darts. These have different properties to darts with rotational symmetry, and they create patterns with a different structure. The experiment analyses the structure of these patterns using contour manipulation.

Hypothesis

The research anticipates that asymmetrical darts will create more complex patterns than symmetrical darts.

Experimental Design

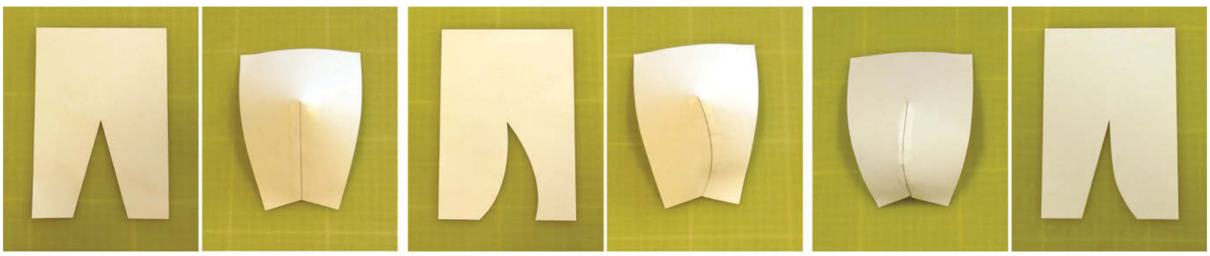
The experiment tests the properties of different configurations of asymmetrical darts. Asymmetrical darts are different to symmetrical darts as the dart legs are not symmetrical (see figure 1). This is achieved by using dart manipulation to de-construct these patterns into a series of darts and gussets. This allows patternmakers to observe their structure.

Part 1 will observe the unique properties of asymmetrical darts as compared to other darts.

Part 2 uses contour manipulation on an asymmetrical dart.

Part 3 uses contour manipulation on asymmetrical darts of concave and convex configurations.

Part 4 uses contour manipulation on a asymmetrical darts of a complex configuration.



Flat 3D Flat 3D Flat 3D

Symmetrical Dart | Symmetrical Dart (Curved dart leg). | Asymmetrical Dart

Figure 1: A symmetrical dart compared to an asymmetrical dart.

Procedure

The experiment consists of four main iterations.

Results

Part 1:

Set 1: Asymmetrical dart with a concave configuration

Create an asymmetrical dart pattern with a concave configuration on a rectangular pattern. Create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. This iteration will show the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 1: Construct the pattern in 3D.

Model 2: Leave as a flat pattern.

Model 3: Construct the pattern in 3D. Draw a line from the middle apex to the top of the pattern. Cut down this line and flatten this pattern.

Model 4: Flatten this pattern to indicate where the line is cut in model 3.

Model 5: Re-create model 3. Then pinch out an apex at the lower apex so that the seam line creates a straight line. This should have flattened the pattern into a series of darts and gussets.

Model 6: Flatten the pattern to show the location of the darts and the gusset.

Set 2: Asymmetrical dart with a convex configuration

Create an asymmetrical dart pattern with a convex configuration on a rectangular pattern. Create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. This iteration will show the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 7: Construct the pattern in 3D.

Model 8: Leave as a flat pattern.

Model 9: Construct the pattern in 3D. Draw a line from the middle apex to the top of the pattern. Cut down this line and flatten this pattern.

Model 10: Flatten this pattern to indicate where the line is cut in model 3.

Model 11: Re-create model 3. Cut a line from the lower apex to the right edge of the pattern. Pivot out a dart at the apex so that the seam line creates a straight line. This should have flattened the pattern into a series of darts.

Model 12: Flatten the pattern to show the location of the darts and the gusset.

Part 2: Asymmetrical dart with a detailed dart leg

Create an asymmetrical dart pattern with a more detailed convex configuration on a rectangular pattern (see figure 4). Create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. This experiment will show the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 13: Construct the pattern in 3D.

Model 14: Cut a line from the top apex to the top of the pattern. Pivot out a dart to flatten the pattern.

Model 15: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it.

Model 16: Move down to the next apex and cut a line from the apex to the edge of the pattern. Pivot the pattern piece so that the edge aligns with the edge next to it. The entire pattern should now be flattened revealing a series of darts.

Part 3: Asymmetrical dart with shaped dart legs

Create an asymmetrical dart pattern with two dart legs of different shapes on a rectangular pattern. Create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. This iteration will show the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 17: Leave as a flat pattern.

Model 18: Construct into a 3D pattern.

Model 19: Cut a line from the top apex to the right edge of the pattern. Pivot out a dart to flatten the pattern.

Model 20: Move down to the next apex and cut a line from the apex to the right edge of the pattern. Pivot out a dart to flatten the pattern.

Model 21: Move down to the next apex and pinch out an apex to flatten the pattern.

Part 4: Detailed curved asymmetrical gussets

Create an asymmetrical dart pattern with two dart legs of different shapes on a rectangular pattern. Create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. This iteration will show the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 22: Construct the pattern in 3D.

Model 23: Flatten the pattern. Identify the apex points on the curve and draw lines from the apex point to the edge of the pattern. At the top apex point draw a line from the apex to the top of the pattern.

Model 24: Construct the previous pattern in 3D to show the locations of the apex points.

Model 25: Start with a copy of model 22 (the 3D pattern).

Model 26: Cut down the style line of the pattern. Cut a line from the top apex to the top edge of the pattern. Pivot the central dart so that the edges of the dart align.

Model 27: Move down to the next apex point and cut a line from the apex to the edge of the pattern. Pivot the edge of the garment so that it aligns with the edge next to it.

Model 28: Move down to the next apex point and cut a line from the apex to the edge of the pattern. Pivot the edge of the garment so that it aligns with the edge next to it.

Model 29: Move down to the next apex point and cut a line from the apex to the edge of the pattern. Pivot the edge of the garment so that it aligns with the edge next to it.

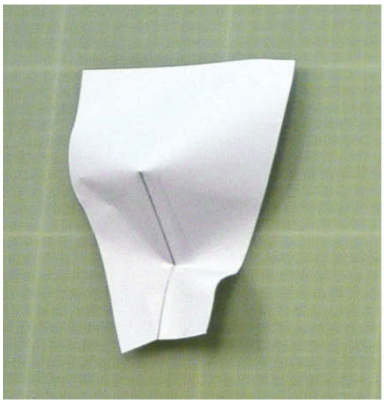
Model 30: Move down to the next apex point and cut a line from the apex to the edge of the pattern. Pivot the edge of the garment so that it aligns with the edge next to it.

Model 31: Move down to the next apex point and cut a line from the apex to the edge of the pattern. Pivot the edge of the garment so that it aligns with the edge next to it. The curved dart is not straightened.

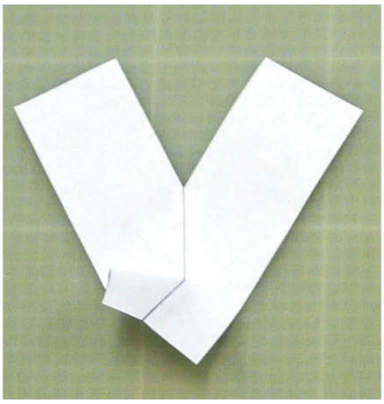
Results

Part 1:

Set 1: Asymmetrical dart with a concave configuration

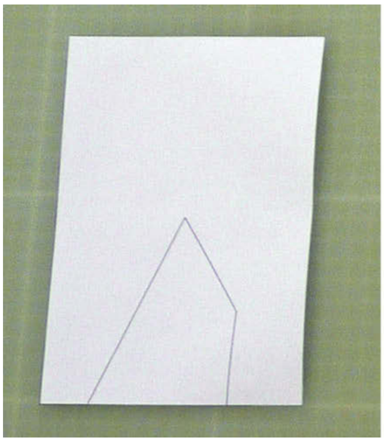


Model 1



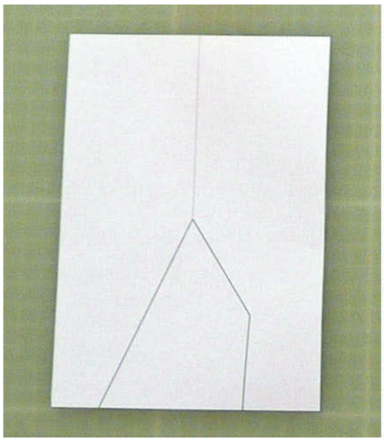
Model 3

Model 5



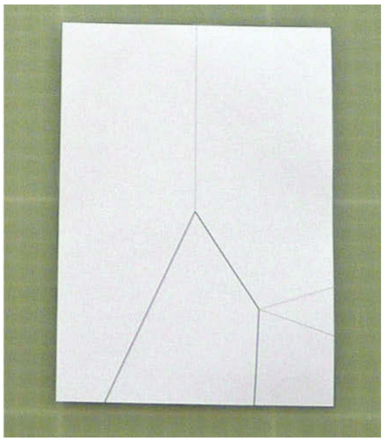
Model 2:

A concave symmetrical dart.



Model 4:

A dart is pivoted out of the central apex.



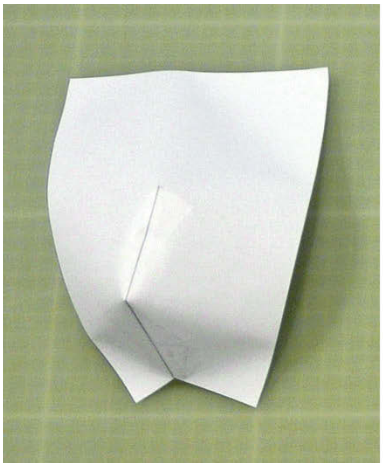
Model 6:

The new gusset is pivoted out of the right apex.

Figure 2: An asymmetrical dart in a concave configuration creates a dart and a gusset.

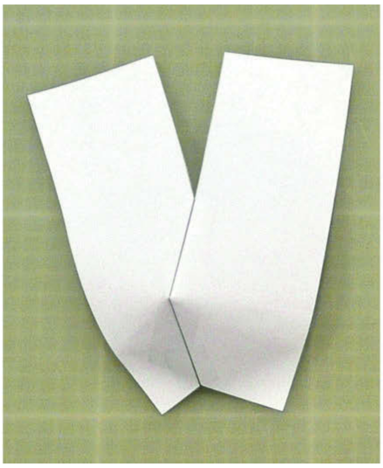
This experiment creates a pattern with a dart and a gusset.

Set 2: Asymmetrical dart with a convex configuration



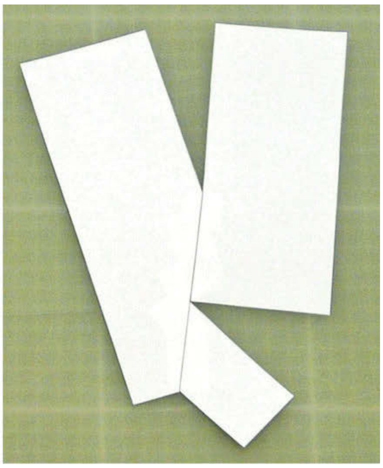
Model 7:

A convex asymmetrical dart.



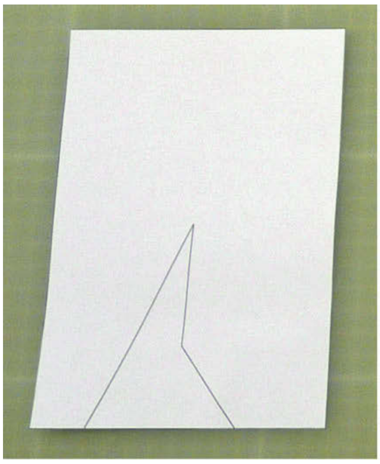
Model 9:

A design line with rotational symmetry.



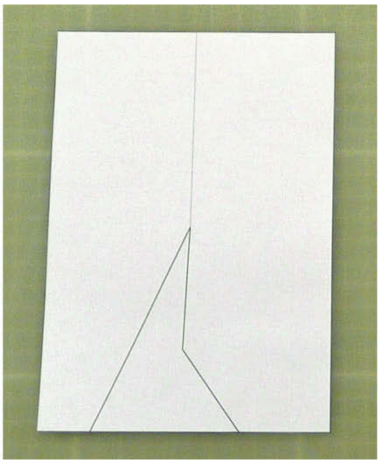
Model 11:

The new dart with a curved design line.



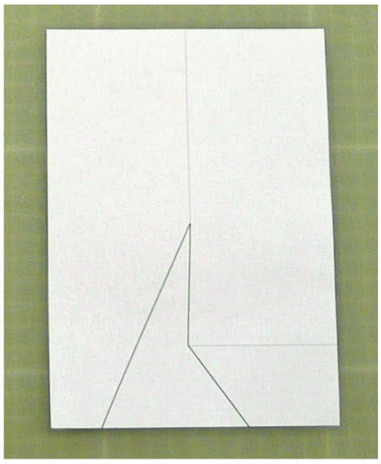
Model 8:

A symmetrical dart.



Model 10:

A dart is pivoted out of the central apex.



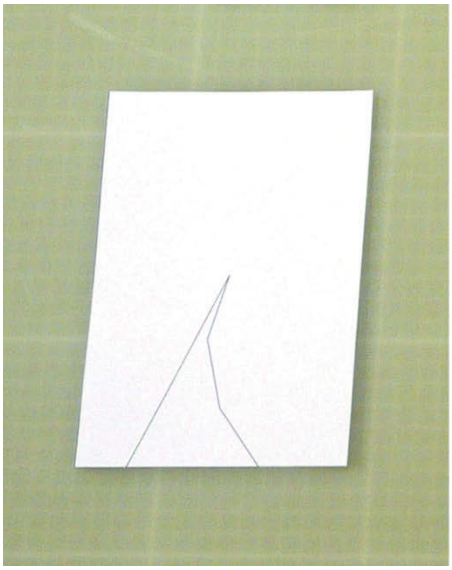
Model 12:

The new dart is pivoted out of the right apex.

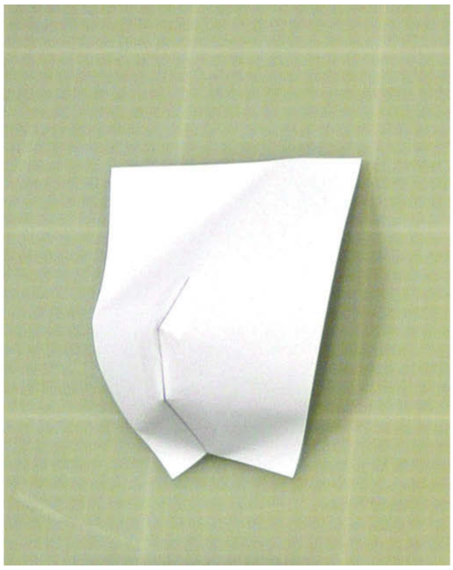
Figure 3: An asymmetrical dart in a convex configuration creates two darts.

This experiment creates a pattern with two darts.

Part 2: Asymmetrical dart with a detailed dart leg



Flat

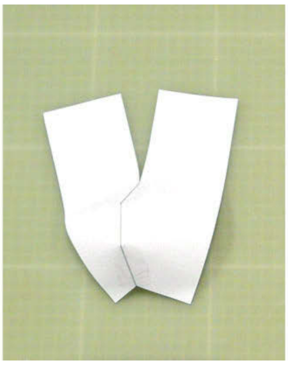


3D

Figure 4: The Asymmetrical dart.

Model 13:

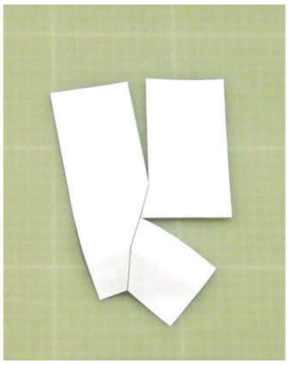
Asymmetrical dart.



Model 14:

Cut and flatten the top apex.

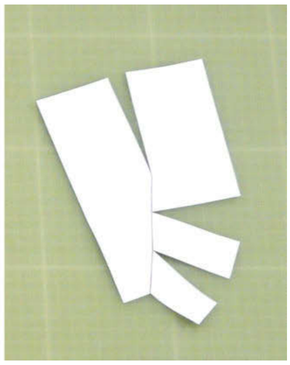
A dart is created.



Model 15:

Cut and flatten the next apex.

A dart is created.



Model 16:

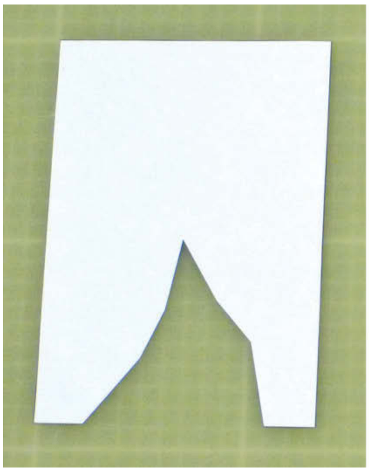
Cut and flatten the final apex.

A dart is created.

Figure 5: The Asymmetrical dart is deconstructed into a series of darts.

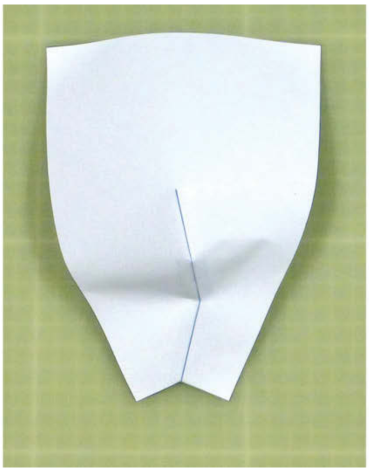
This experiment creates a pattern with three darts.

<u>Part 3</u>: Asymmetrical gusset with shaped dart legs



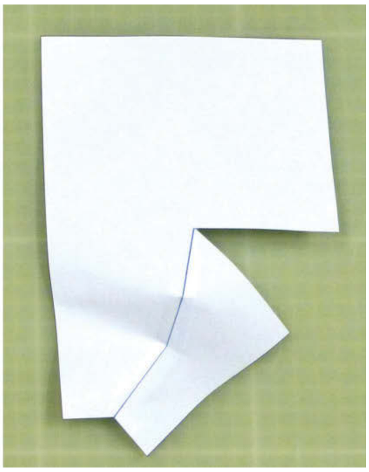
Model 17:

Asymmetrical dart flat pattern.



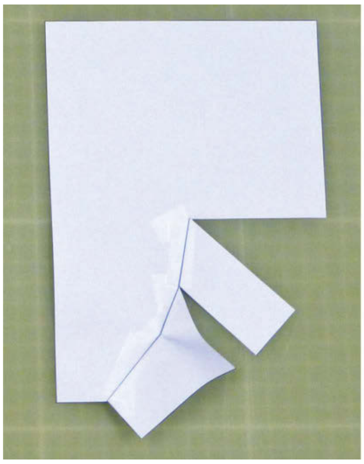
Model 18:

Asymmetrical dart in 3D.



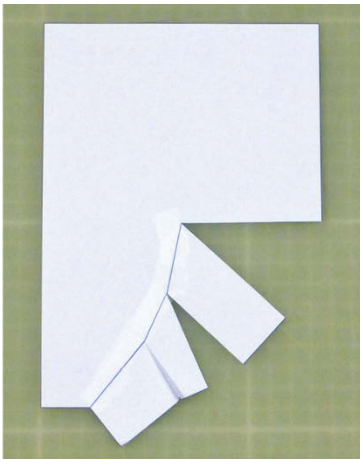
Model 19:

A dart is pivoted out of the central apex.



Model 20:

A dart is pivoted out of the middle right apex.



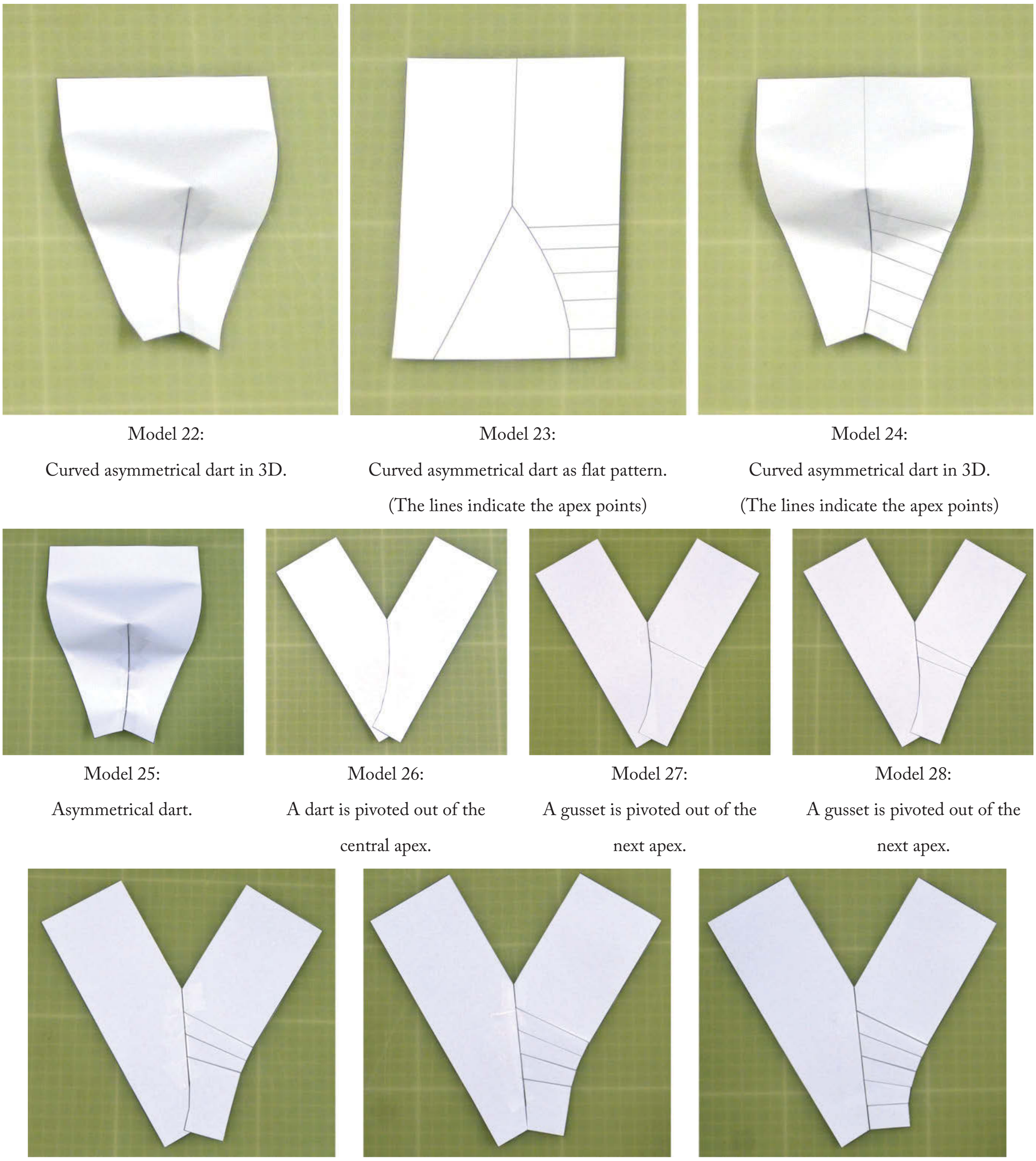
Model 21:

A gusset is pivoted out of The bottom right apex.

Figure 6: This asymmetrical dart created two darts and gusset.

This experiment creates a pattern with two darts and a gusset.

Part 4: Detailed curved asymmetrical gussets



Model 22: Curved asymmetrical dart in 3D.

Model 23: Curved asymmetrical dart as flat pattern. (The lines indicate the apex points)

Model 24: Curved asymmetrical dart in 3D. (The lines indicate the apex points)

Model 25: Asymmetrical dart.

Model 26: A dart is pivoted out of the central apex.

Model 27: A gusset is pivoted out of the next apex.

Model 28: A gusset is pivoted out of the next apex.

Model 29: A gusset is pivoted out of the next apex.

Model 30: A gusset is pivoted out of the next apex.

Model 31: A gusset is pivoted out of the final apex.

Figure 7: This asymmetrical dart can be deconstructed into a dart and a series of gussets.

This experiment creates a pattern with a dart and five segments that overlap like gussets.

Conclusion

The experiment demonstrates that asymmetrical darts can hold more apex points than symmetrical darts. They are more "complex", that is: they have more apex points in a small area, allowing them to change the structure of a pattern more than a symmetrical dart. Different configurations of asymmetrical darts can create darts and gussets. Detailed curves can also create many apex points which shape the pattern. This means that designers who understand the structure of asymmetrical darts can use these to shape a pattern with greater detail than a symmetrical dart.

Experiment 17: Symmetrical and Asymmetrical Darts

Rationale

This experiment compares symmetrical and asymmetrical darts so that it can explore how to design style lines on them while creating patterns with geometric equivalence. Some darts have rotational symmetry and others are asymmetrical. The experiment demonstrates the difference between these types of darts and how to design style lines on them. Observations can be made by comparing different types of dart pattern.

Hypothesis

The research anticipates symmetrical and asymmetrical darts should behave in different ways.

Experimental Design

The experiment is designed to compare the properties of asymmetrical and symmetrical darts in order to observe their properties. The first part examines the different between symmetrical and asymmetrical darts, while the second part shows how to design style lines on symmetrical darts. The third part investigates how to design style lines on asymmetrical darts, and the fourth compares different types of darts and makes observations about their properties.

Procedure

The experiment has four parts.

<u>Part 1</u>: Comparing symmetrical and asymmetrical darts

Set 1: Dart symmetry

The aim is to observe the properties of symmetrical darts.

Create 3 different types of symmetrical model making two copies of each. Print them from the same digital file on 80 gsm paper.

Model 1: Create a straight edge symmetrical dart.

Model 2: Create a curved edge symmetrical dart.

Model 3: Create a wavy edge symmetrical dart.

Model 4: Create a straight edge symmetrical dart. Trace the edge of the curve and pivot the curve to show the symmetry of the pattern.

Model 5: Create a curved edge symmetrical dart. Trace the edge of the curve and pivot the curve to show the symmetry of the pattern.

Model 6: Create a wavy edge symmetrical dart. Trace the edge of the curve and pivot the curve to show the symmetry of the pattern.

Set 2: Rotational symmetry

The aim of this experiment is to demonstrate the way that darts can be designed with rotational symmetry and maintain the same size of pattern.

Create multiple identical copies of a rectangular pattern with a symmetrical dart. Print them from the same digital file on 80 gsm paper.

Model 7: Construct the pattern in 3D. Identify the straight seam line.

Model 8: Cut down the seam line and flatten the pattern.

Model 9: Construct the pattern in 3D. Draw a wavy design line from the apex point to the edge of the pattern.

Model 10: Cut down the seam line and flatten the pattern.

Set 3: Designing on symmetrical darts

The aim of this iteration is to demonstrate a way that darts can be designed with rotational symmetry while maintaining the same size of pattern.

Create multiple identical copies of a rectangular pattern with a symmetrical dart. Print them from the same digital file on 80 gsm paper. Each model will be recorded as a 3D pattern and a flat pattern.

Model 11: Construct the pattern in 3D. Flatten the pattern.

Model 12: Draw a curve line from the apex to the edge of the pattern. Cut down the style line and flatten the pattern.

Model 13: Draw a curve line with a rectangular wedge in it from the apex to the edge of the pattern. Cut down the style line and flatten the pattern.

Model 14: Draw a wavy line from the apex to the edge of the pattern. Cut down the style line and flatten the pattern.

Model 15: Draw a line with smaller waves from the apex to the edge of the pattern. Cut down the style line and flatten the pattern.

Part 2: Designing on symmetrical and asymmetrical darts

Set 4: Designing on symmetrical darts

The aim of this experiment is to compare designing on symmetrical darts compared to asymmetrical ones. It designs a style line on a symmetrical pattern. Create two copies of a rectangular pattern with a symmetrical dart. Print them from the same digital file on 80 gsm paper.

Model 16: Leave as a flat pattern.

Model 17: Draw the desired style line on the flat pattern from the apex point to the edge of the garment. Trace this curve and pivot the curve so that it has rotational symmetry with the other side of the pattern.

Model 18: Cut down the design line to create the new pattern with the curved design line.

Set 5: Designing on asymmetrical darts

The aim of this experiment is to compare designing on a symmetrical dart compared to an asymmetrical one.It designs a style line on an asymmetrical pattern. Create two copies of a rectangular pattern with an asymmetrical dart. Print them from the same digital file on 80 gsm paper.

Model 19: Leave as a flat pattern.

Model 20: Draw the desired style line on the flat pattern from the apex point to the edge of the garment. Trace this curve and pivot the curve so it has rotational symmetry with the other side of the pattern.

Model 21: Cut down the seam line and flatten the pattern.

Part 3: Comparing symmetrical and asymmetrical darts

Set 6: The apex points in symmetrical and asymmetrical darts

The aim of this experiment is to compare the numbers of apex points created by symmetrical and asymmetrical darts.

Create a straight edge symmetrical dart, a curved edge symmetrical dart and an asymmetrical dart. Create two copies of each pattern. Print them from the same digital file on 80 gsm paper.

Model 22: Create a straight edge symmetrical dart in 3D and as a flat pattern. Identify the number of apex points on the pattern.

Model 23: Create a curved edge symmetrical dart in 3D and as a flat pattern. Identify the number of apex points on the pattern.

Model 24: Create an asymmetrical dart with one leg straight and the other curved in 3D and as a flat pattern. Identify the number of apex points on the pattern.

Results

Part 1: Comparing symmetrical and asymmetrical darts

Set 1: Dart symmetry

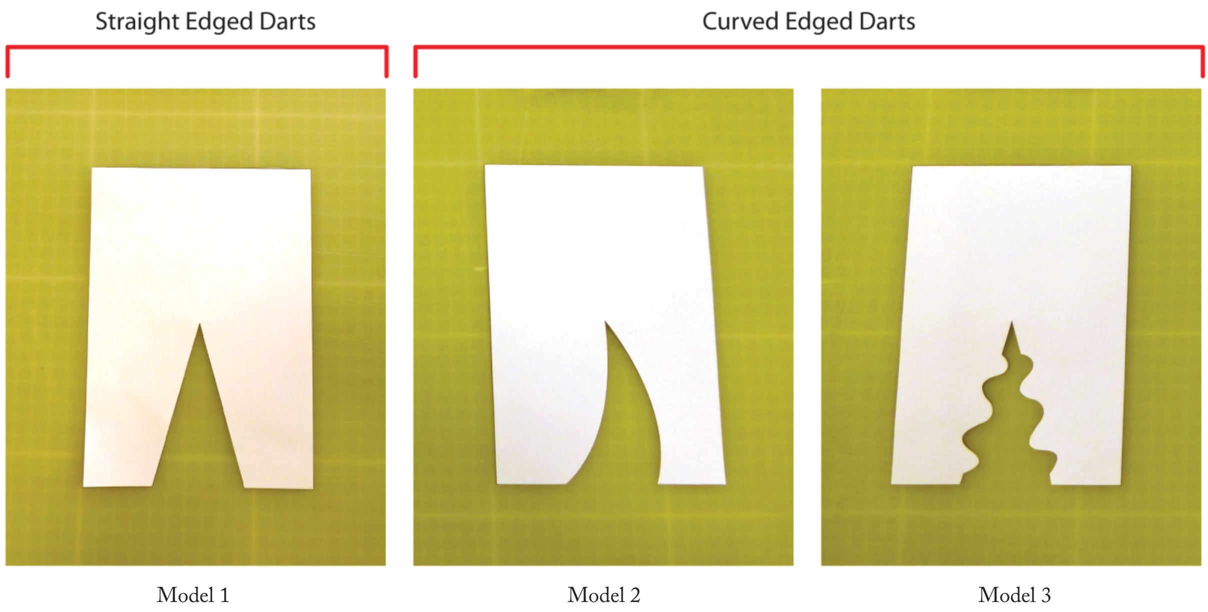


Figure 1: Straight edged dart and curved dart.

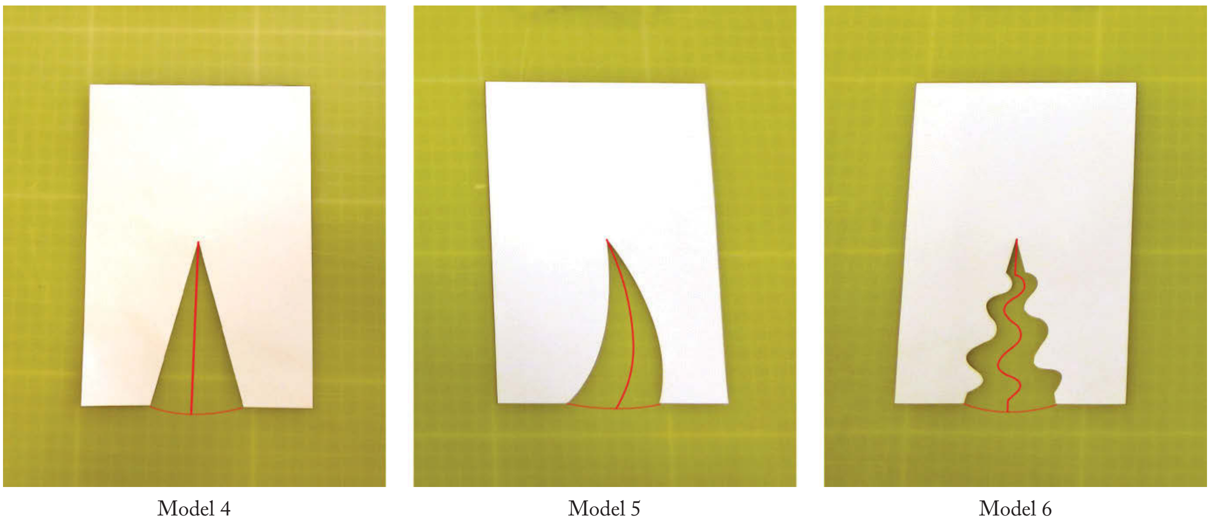
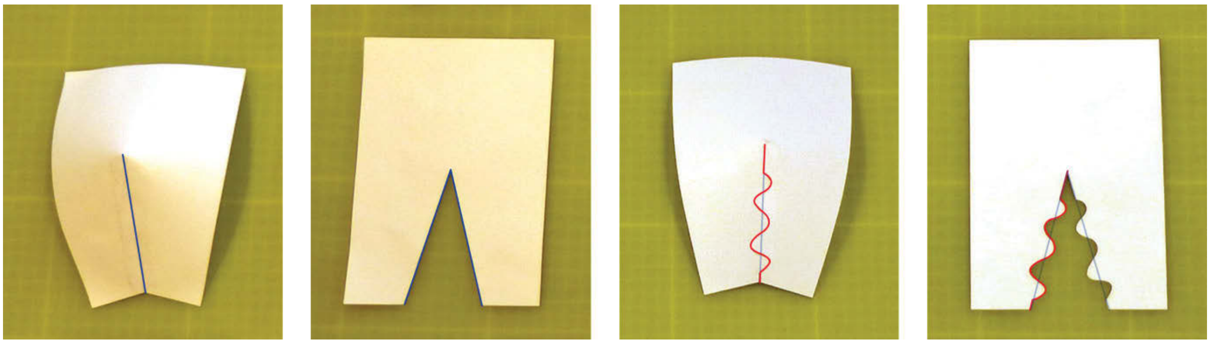


Figure 2: Show that straight and curved edges all have rotational symmetry.

Set 2: Rotational Symmetry

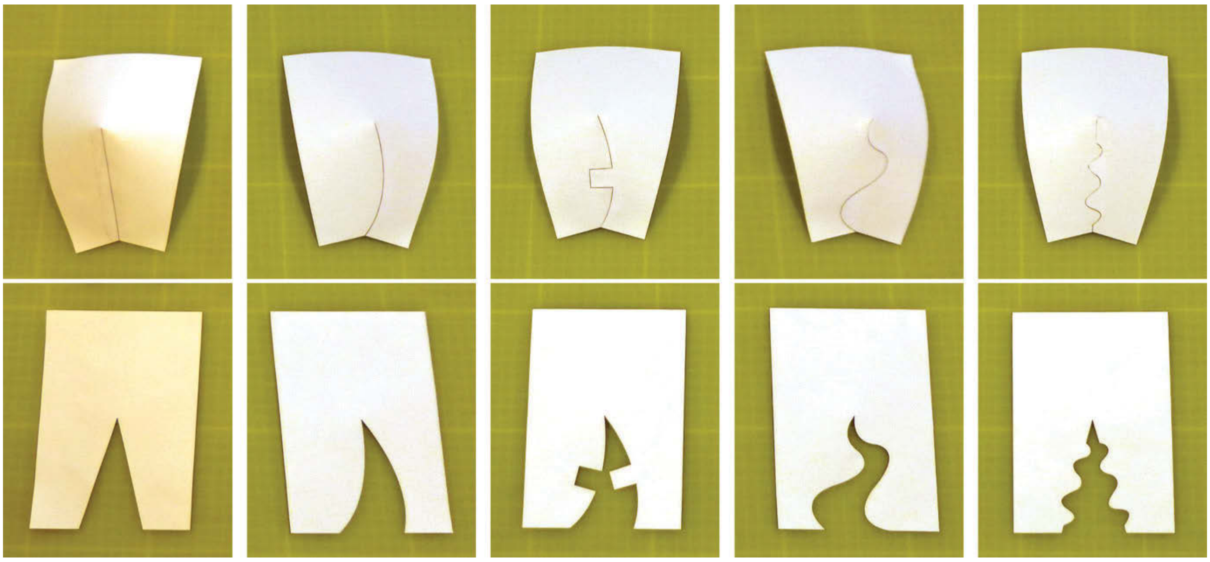


Model 7 | Model 8 | Model 9 | Model 10

A straight edged symmetrical dart. | A wavy edged symmetrical dart.

Figure 3: A dart with any shaped dart leg is created by drawing a curved line from the apex to the dart edge and cutting it out.

Set 3: Designing on symmetrical darts



Model 11: A straight edge dart

Model 12: A dart with a curved dart leg.

Model 13: A dart with a curved dart leg.

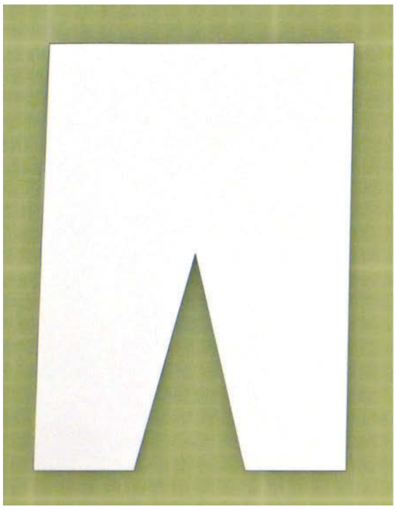
Model 14: A dart with a curved dart leg.

Model 15: A dart with a curved dart leg.

Figure 4: Drawing a line on a straight edge dart and cutting it out makes it possible to make almost any shape of dart.
As long as the curve is cut from the apex to edge of the garment, they will all maintain the same three-dimensional shape.

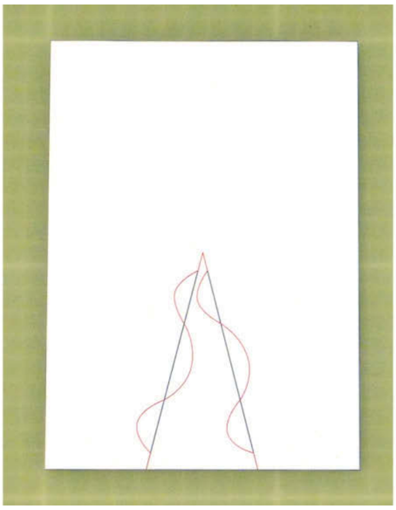
Part 2: Designing on symmetrical and asymmetrical darts

Set 4: Designing on symmetrical darts



Model 16:

A symmetrical dart.



Model 17:

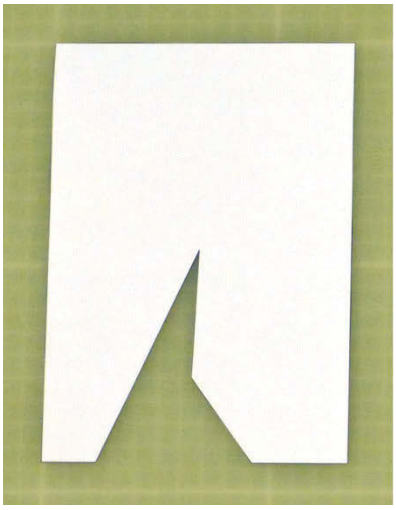
A design line with rotational symmetry is drawn on the dart.

Model 18:

The new dart with a curved design line, geometrically equivalent to the original.

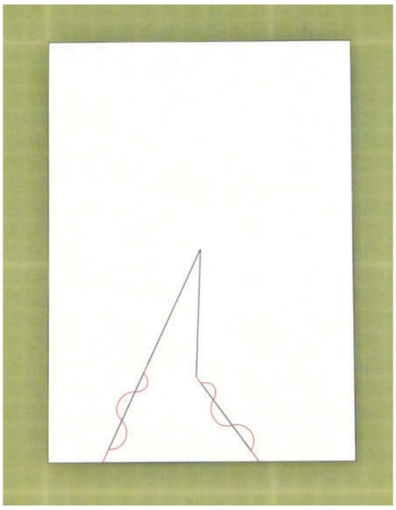
Figure 5: Designing a style line on a dart with rotational symmetry.

Set 5: Designing on asymmetrical darts



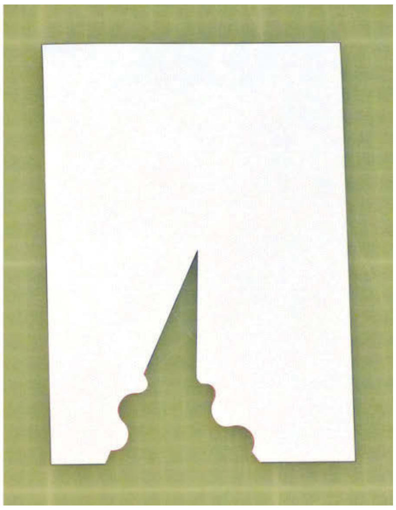
Model 19:

An asymmetrical dart.



Model 20:

A curved design line with rotational symmetry is drawn from the apex to the edge of the pattern.



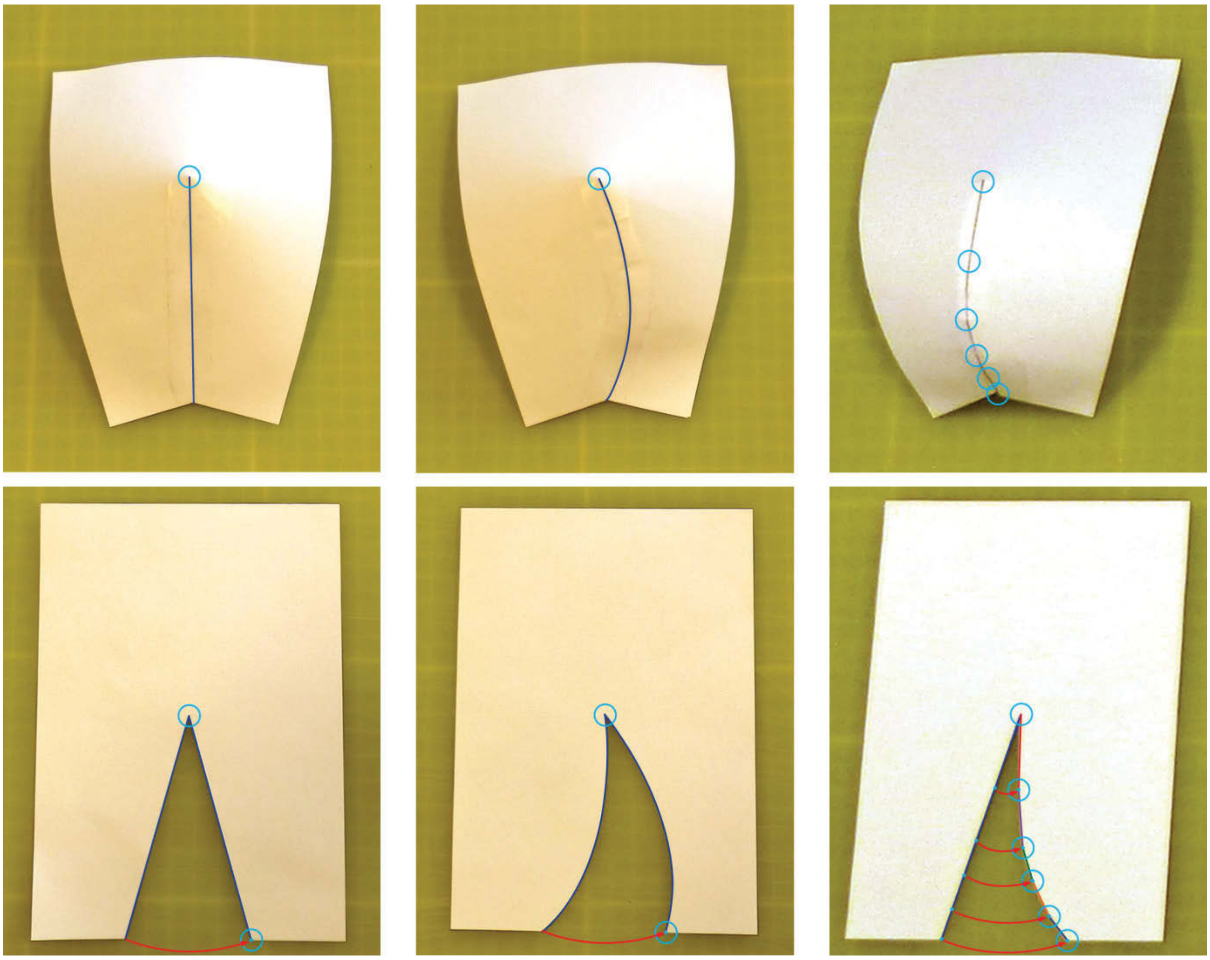
Model 21:

The new dart is still an asymmetrical dart. It has a curved design line, still geometrically equivalent to the original.

Figure 6: An asymmetrical dart can have rotational symmetry.

Part 3: Comparing symmetrical and asymmetrical darts

Set 6: The apex points in symmetrical and asymmetrical darts



Model 22:
A symmetrical dart has a single apex.

Model 23:
A curved dart with rotational symmetry has a single apex.

Model 24:
An asymmetrical dart has multiple apex points.

Figure 7: An asymmetrical dart is different to a curved dart with rotational symmetry.

Conclusion

The experiment demonstrates that symmetrical darts have rotational symmetry, while asymmetrical darts have the potential to create more apex points than symmetrical darts.

Experiment 18: Asymmetrical Gussets

Rationale

This experiment explores the properties of asymmetrical gussets by using contour manipulation to flatten the pattern into a series of apex points with darts and gussets.

Hypothesis

The research anticipates that asymmetrical gussets create a series of smaller gussets when flattened.

Experimental Design

It explores the properties of asymmetrical gussets whereby an asymmetrical gusset pattern is created and then flattened using contour manipulation.

Procedure

Create an asymmetrical gusset that is curved. Insert it into a rectangular pattern. To ensure the pattern has the same length as the asymmetrical dart, trace the edge of the pattern on the top edge of the rectangular pattern. Then cut down this line and insert the dart (see figure 1). Create 6 identical copies of this pattern. Print them from the same digital file on 80 gsm paper and construct them in 3D using tape. This experiment shows the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 1: Construct the pattern in 3D.

Model 2: On the bottom left apex pinch out a gusset to flatten the pattern.

Model 3: Move up to the next apex and pinch out a gusset to flatten the pattern.

Model 4: Move up to the top apex and pinch out a gusset to flatten the pattern.

Model 5: Move across to the middle apex on the right side of the pattern. Pinch out an apex to flatten the pattern.

Model 6: Move up to the top right apex and pinch out a gusset to flatten the pattern.

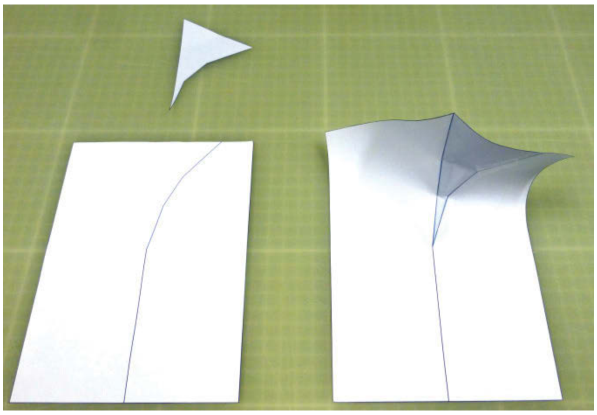
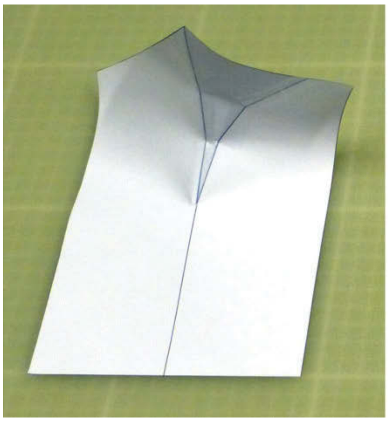


Figure 1: Asymmetrical gussets, with both sides of the gusset asymmetrical to the pattern it is inserted into.

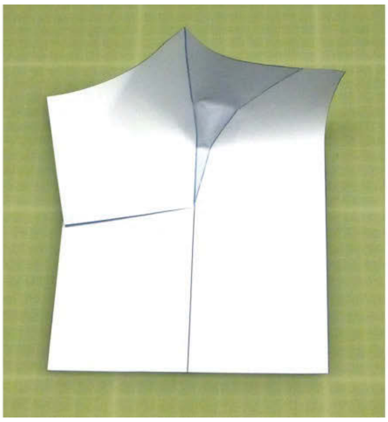
Results

Set 1:



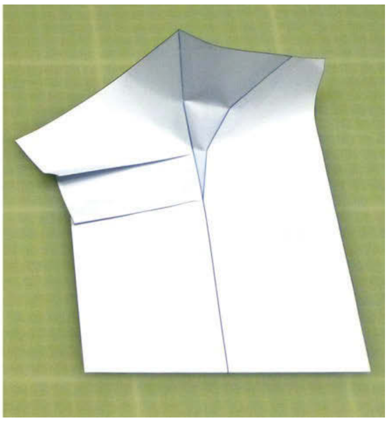
Model 1:

Asymmetrical gusset.



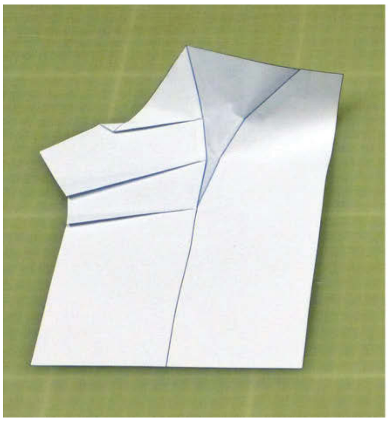
Model 2:

A gusset is pivoted out of the central apex.



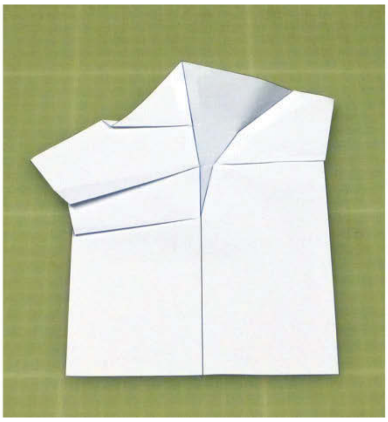
Model 3:

A gusset is pivoted out of the middle left apex.



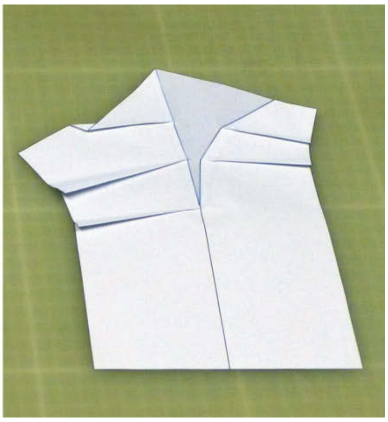
Model 4:

A gusset is pivoted out of the top left apex.



Model 5:

A gusset is pivoted out of the middle right apex.



Model 6:

A gusset is pivoted out of the top right apex.

Figure 2: Asymmetrical gussets can create more apex points than an asymmetrical dart of a similar shape. This asymmetrical gusset creates five apex points.

This iteration creates five gussets at five apex points. It observes that an asymmetrical gusset has two different seam lines where apexes can be placed. This constitutes twice as many seam lines as an asymmetrical gusset.

Conclusion

The experiment shows that an asymmetrical gusset pattern can be deconstructed into a series of apex points and gussets. An asymmetrical gusset has a unique property in that it creates two seam lines compared to an asymmetric gusset, which has only one. This offers twice as many sites for apex points and allows the patternmaker to create more detailed patterns by using asymmetrical gussets.

Experiment 19: Curved Contour Lines in Contour Manipulation

Rationale

This experiment uses a curved contour line in contour manipulation. In previous experiments with contour manipulation a curved seam line is flattened onto a straight line that runs down the centre of the seam line. There is also a way of manipulating contours by flattening the pattern with the curved contour line on one side of a curve. The experiment shows how to use contour manipulation on curved contour lines.

Hypothesis

The research anticipates that flattening the pattern on a curve will create a faster transformation. This is because only half of the pattern has to be manipulated, requiring half the number of manipulations.

Experimental Design

The experiment shows how to use contour manipulation on a curved line instead of straightening both sides of a curve into a straight line. It is tested in three parts. The first part takes an asymmetrical dart and manipulates the pattern onto the straight edge of one of the dart legs. This pattern will be on a straight line that does not run down the centre of the pattern. The second part will apply a curved contour manipulation on a convex dart. The third part will apply a curved contour manipulation on a concave gusset pattern.

Procedure

The experiment has three sets of iterations.

Curved asymmetrical darts create darts and gussets

Set 1:

Create an asymmetrical dart pattern in which one dart leg is straight and the other is a zig-zag shape on a rectangular pattern. Create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. The experiment shows the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 1: Construct the pattern in 3D.

Model 2: Leave as a flat pattern.

Model 3: Construct the pattern in 3D. Draw a line from the middle apex to the top of the pattern. Cut down this line and flatten this pattern.

Model 4: Flatten this pattern to indicate where the line is cut in model 3.

Model 5: Re-create model 3. Move down to the apex second from the top and pinch out a gusset to flatten the apex point.

Model 6: Flatten the pattern to show the location of the darts and the gusset.

Model 7: Re-create model 5. Move down to the apex third from the top and cut a line from the apex to the right side of the pattern. Pivot a dart out to flatten the pattern.

Model 8: Flatten the pattern to show the location of the darts and the gussets.

Model 9: Re-create model 7. Move down to the apex on the bottom of the pattern and pinch out a gusset to flatten the apex point. This should flatten the entire pattern.

Model 10: Flatten the pattern to show the location of the darts and the gussets.

Set 2:

Create a pattern with a convex dart on a rectangular pattern. Create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. The experiment shows the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 11: Construct the pattern in 3D.

Model 12: Leave as a flat pattern.

Model 13: Cut a line down the seam line of the pattern. Cut a seam line from the central apex to the top of the pattern. Flatten the central apex and create a dart. Join the edges of the pattern just under the central apex.

Model 14: Flatten this pattern to indicate the location of the dart in model 13.

Model 15: Re-create model 13. Move down to the apex second from the top and cut a line from the apex to the left edge of the garment to flatten the pattern.

Model 16: Flatten the pattern to show the location of the darts and the gusset.

Model 17: Re-create model 15. Move down to the apex third from the top and cut a line from the apex to the right side of the pattern. Pivot a dart out to flatten the pattern. The entire pattern should now be flattened.

Model 18: Flatten the pattern to show the location of the darts and the gussets.

Set 3:

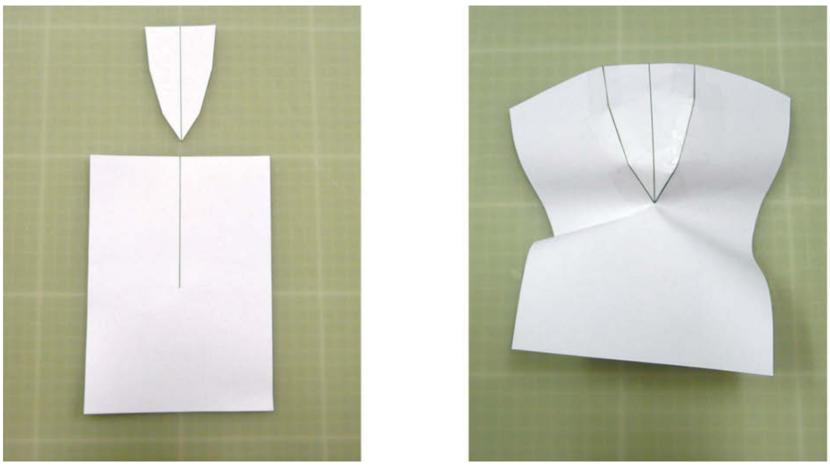
Create a pattern with a concave gusset being inserted into a rectangular pattern (see figure 1). Create multiple identical copies of this pattern and print them from the same digital file on 80 gsm paper. The experiment shows the transformation as a series of paper models. Start each model with a copy of the previous model, then add the additional transformations.

Model 19: Construct the pattern in 3D.

Model 20: At the central apex pinch out a gusset to flatten the pattern.

Model 21: Cut a line from the apex second from the bottom to the left edge of the pattern. Pivot out a dart to flatten the pattern.

Model 22: Move ups an apex and cut a line from the top apex to the left edge of the pattern. Pivot out a dart to flatten the pattern. The entire pattern should now be flattened.

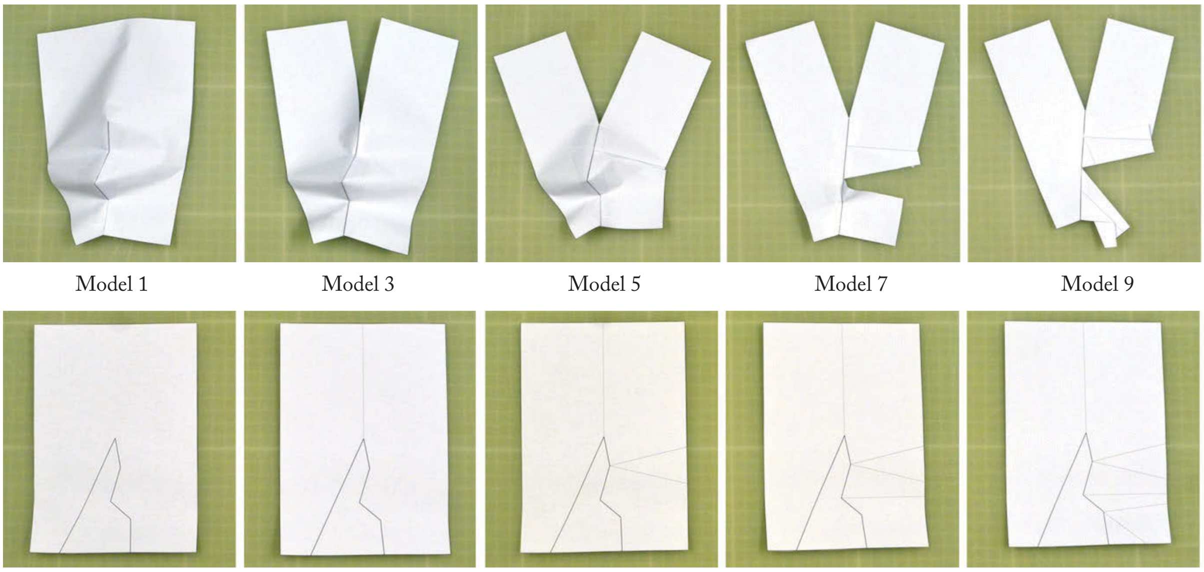


Flat 3D

Figure 1: A concave gusset pattern created by inserting a gusset into a rectangular pattern.

<u>**Results**</u>

Set 1:



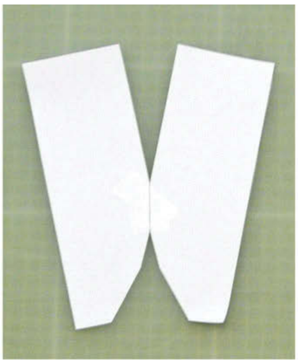
Model 1	Model 3	Model 5	Model 7	Model 9
Model 2: A complex asymmetrical dart.	Model 4: A dart pivoted out of the central apex.	Model 6: A gusset pinched out of next apex.	Model 8: A dart pivoted out of the next apex.	Model 10: A gusset pinched out of the next apex.

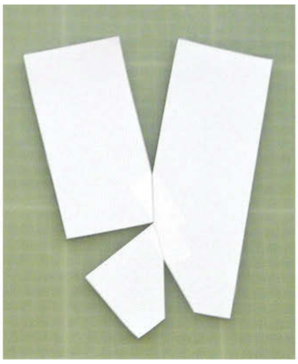
Figure 2: An asymmetrical dart manipulated onto a straight line.

This pattern creates two gussets and two darts.

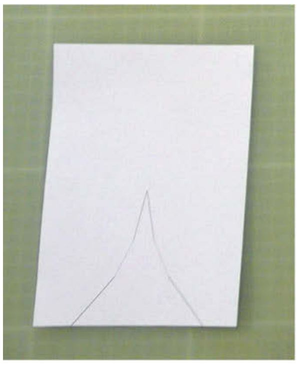
Set 2: Using a curved contour line in contour manipulation

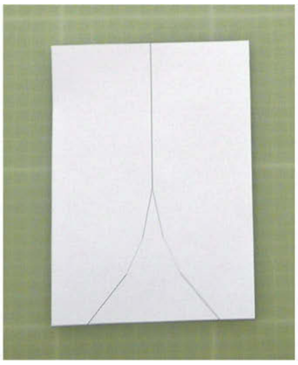

Model 11

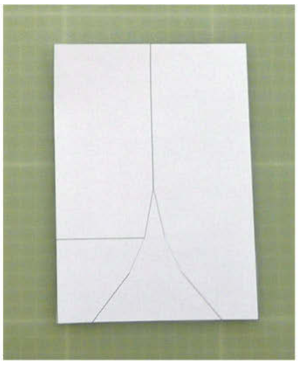

Model 13


Model 15


Model 17


Model 12:
A convex dart.


Model 14:
A dart is created at the central apex.


Model 16:
A dart is created at the middle left apex.

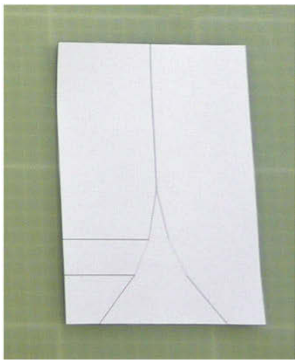
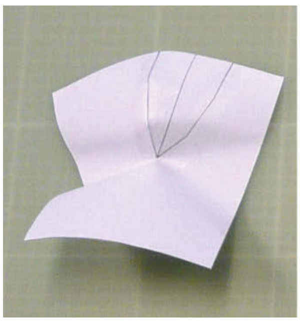
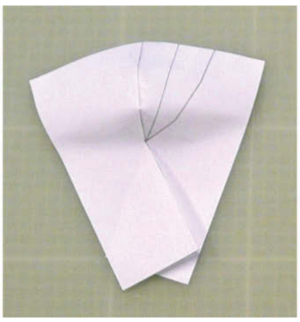

Model 18:
A dart is created at the bottom left apex.

Figure 3: A convex dart is manipulated so that the pattern lies on a curved line.

This pattern creates two darts.

Set 3:


Model 19:
A straight edge dart.


Model 20:
A dart with a curved dart leg.


Model 21:
A dart with a curved dart leg.


Model 22:
A dart with a curved dart leg.

Figure 4: A gusset manipulated sot that the pattern lies on a curved line.

This pattern creates a gusset and two darts.

Conclusion

The experiment demonstrates that it is possible to use contour manipulation on a pattern where the contour does not have a straight line. This is another way of deconstructing a pattern and finding its properties. One advantage of this technique is that each apex point only has one dart or gusset. This creates fewer darts and gussets and makes the process faster.

6. Exploring Traditional Bust Point Manipulation

Experiment 20: **Testing the dart angles of traditional bust point dart manipulation**

Experiment 21: **Surface area of traditional bust point dart manipulation**

Experiment 22: **Using geometry to show a change in surface area**

Aim

This group of experiments tests the technique of bust point manipulation to discern whether moving the location of the apex changes the properties of the dart. It investigates how moving the location of the dart affects the apex location, dart angle and surface area of the pattern. To test how bust point manipulation affects the garment' surface area, it uses computer software to check the measurements. It also offers a proof using trigonometry, to see whether traditional bust point manipulation moves the location of the dart.

Method

The first experiment tests the properties of bust point manipulation and how moving the location of the dart can change the angle of the dart. The second experiment looks at how bust point manipulation can change the surface area of a garment, by using 3D computer software to measure the surface area of the patterns. The third experiment uses trigonometry to explain how changing the dart angle of the pattern changes the surface area of the garment.

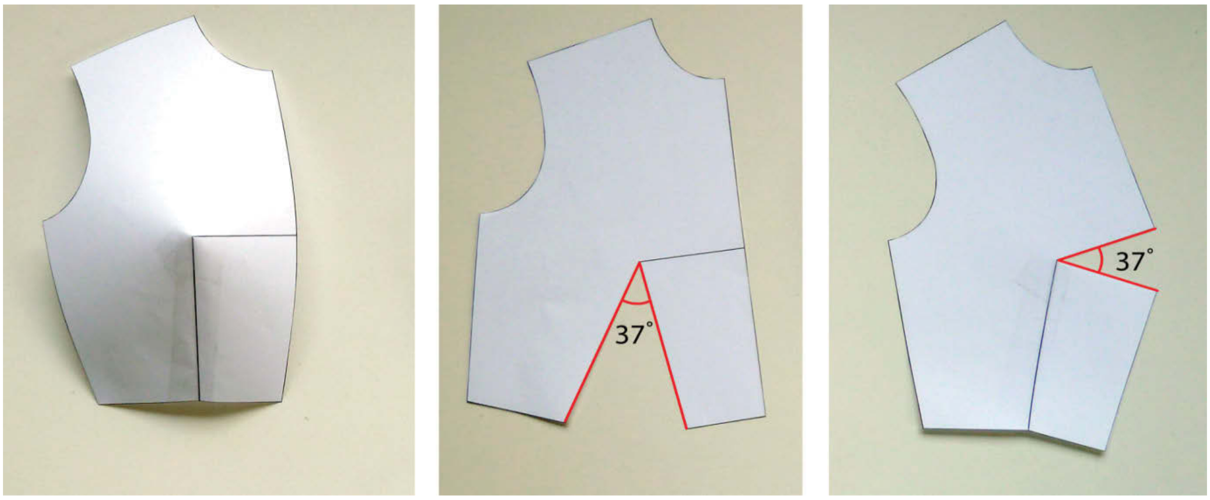
Analysis

Traditional bust point manipulation is a commonly-used way to move darts around bust point while keeping the garment's original fit. Geometric analysis reveals that this technique moves the location of the apex point and changes the dart angle depending on the length of the dart leg. In effect, it changes the three-dimensional form and the fit of the garment. Computer software analysis of the patterns demonstrates that moving the apex and altering the dart angles changes the garment's surface area. Thereby, the concluding experiment in this group provides a trigonometric proof that changing the dart angle changes the surface area of the pattern. Traditional bust point manipulation seeks to create a pattern that is similar to the original, yet from a geometric perspective it is not the same shape or fit. This offers us a chance to deliver an alternative technique that maintains greater geometric equivalence.

Experiment 20: Testing the Dart Angles of Traditional Bust Point Dart Manipulation

Rationale

This experiment tests whether the dart angles change size when applying the technique of bust point manipulation. This is a commonly-used technique in patternmaking literature in which the apex point of a dart is moved when a dart is moved. In most dart manipulation the apex point of a dart is not moved (see figure 1). In bust point manipulation the apex point is moved, because if the dart were left at bust point it would create an undesirable cone shape on the bust (see figure 2). The experiment tests whether moving the apex point changes the dart angle of the pattern.



3D Model. | Flat pattern: Cut through bottom dart. | Flat pattern: Cut through side dart.

Figure 1: In dart manipulation the apex of the pattern is not moved.

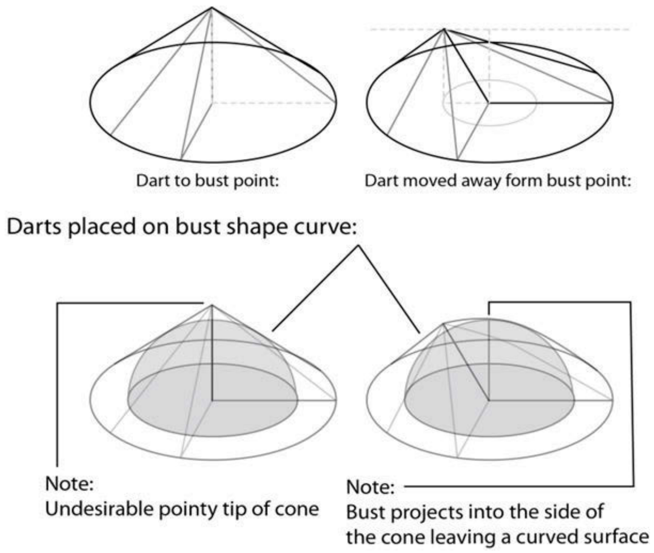


Figure 2: Bust point dart manipulation moves the apex point so that the pattern does not have an undesirable pointy shape.

Hypothesis

The research anticipates that moving the apex location of a dart will change its dart angle.

Experimental Design

The experiment tests the dart angles of a pattern before and after using a bust point manipulation. It has two parts. The first replicates, from a patternmaking book, the technique of bust point dart manipulation. The second uses this technique to create patterns with darts in many locations on the same pattern. These patterns then have their darts measured, and observations are made. The patterns are made with third scale so that the measurements may be different from full scale. However, the geometric relationships are the same.

Procedure

This experiment consists of two parts.

Results

Part 1: Replicate the technique in patternmaking literature

Apply the bust point manipulation technique from Assembil's (2013, p. 293) patternmaking book and use it on a garment pattern (see figure 3). It moves a bust point dart from one location to another. The experiments should be drawn on paper.

Model 1: Start with a basic block pattern with a bust dart which has its apex moved away from bust dart. The distance from bust dart is indicated by the circle drawn on the pattern. The dart drawn with the dashed line is the dart with an apex at bust point.

Model 2: Identify the location of bust point and move the dart to bust point.

Model 3: Draw the location of the new bust dart to the edge of the pattern on the right side of the garment.

Model 4: Cut through the dart and the new style line. Then pivot the dart moving the location of the dart.

Model 5: A new dart is created in a new location with its apex at bust point.

Model 6: The apex of the dart is moved away from bust point the same amount as the original pattern. This distance is shown by the circle drawn on the pattern. This is the final bust dart.

Part 2: Measure the dart angles

Using the technique in part 1, new bust point patterns are created in different locations. All models start with model 1 and using the bust point dart manipulation technique the darts are moved to a new location.

Model 7: Using the bust point manipulation move a new dart to the waist of the garment.

Model 8: Using the bust point manipulation move a new dart to the side seam of the garment.

Model 9: Using the bust point manipulation move a new dart to the armhole of the garment.

Model 10: Using the bust point manipulation move a new dart to the centre front waist of the garment.

Model 11: Using the bust point manipulation move a new dart to the middle of the shoulder of the garment.

Model 12: Using the bust point manipulation move a new dart to the tip of the shoulder of the garment.

Model 13: Using the bust point manipulation move a new dart to the make a French dart on the garment.

Model 14: Using the bust point manipulation move a new dart to the centre front of the garment.

Once these models are constructed, observe their 3D and flat patterns. Then measure the dart angles of each of the patterns.

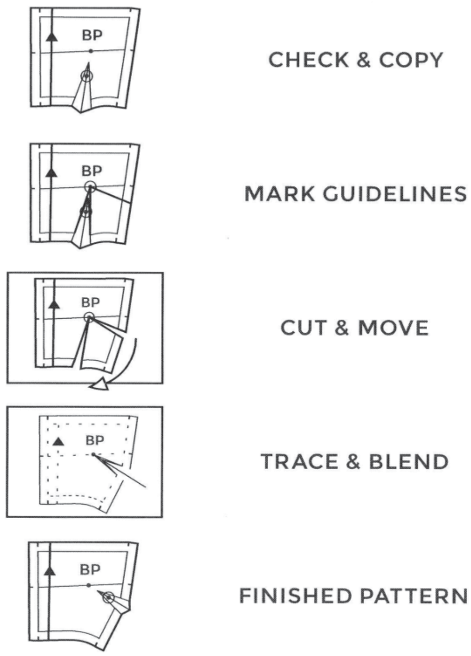
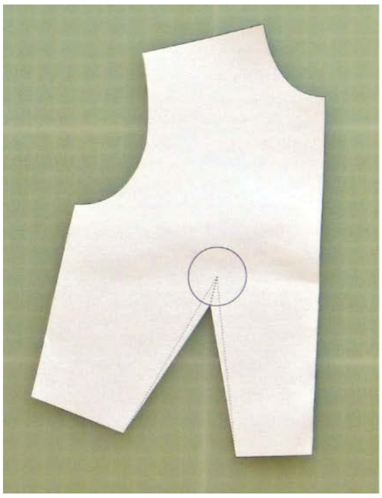


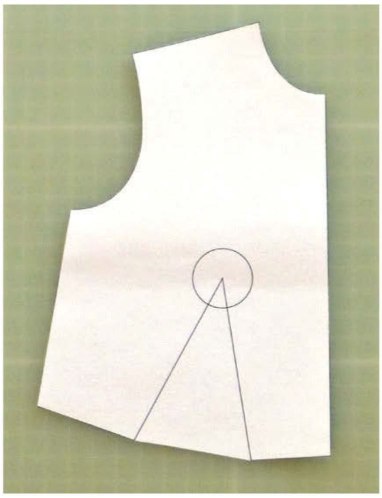
Figure 3: This diagram demonstrates dart manipulation around bust point using the "cut and spread" technique (Assembil 2013, p. 293). There is another version of this technique called the "pivot", which achieves the same geometric effect.

Results

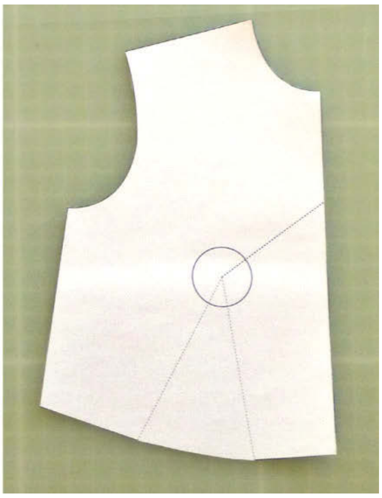
Part 1: Replicate the technique in patternmaking literature



Model 1:
The dart is a uniform distance from bust point.

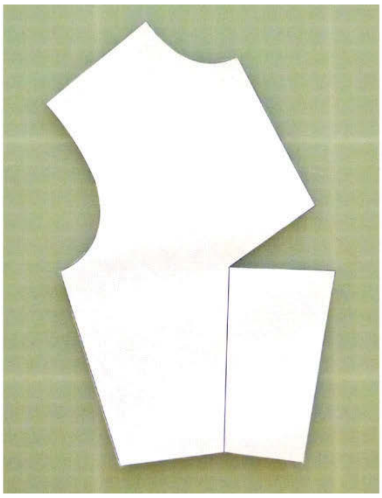


Model 2:
The dart at bust point is located.

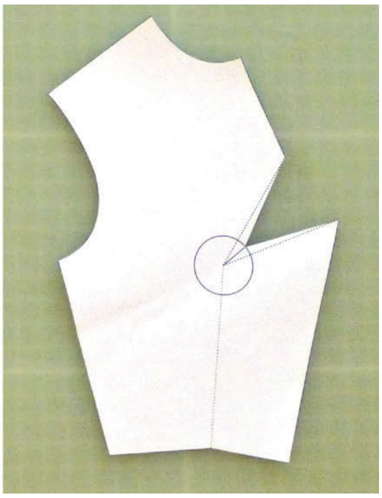


Model 3:
The new dart location is drawn from bust point to the edge of the pattern.

Model 4:
The dart is pivoted around bust point.



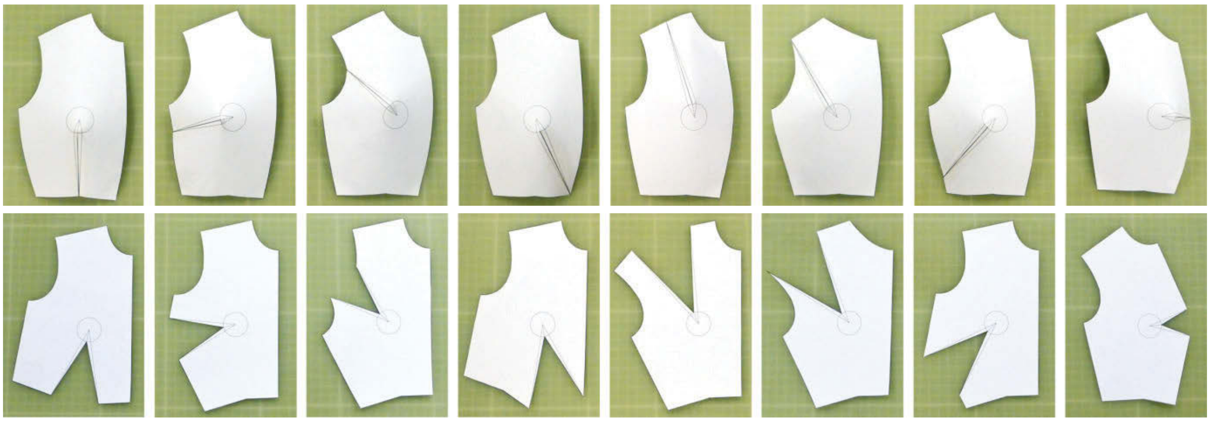
Model 5:
A new dart is created in a new location.



Model 6:
The final dart is created by moving the dart a uniform distance from bust point.

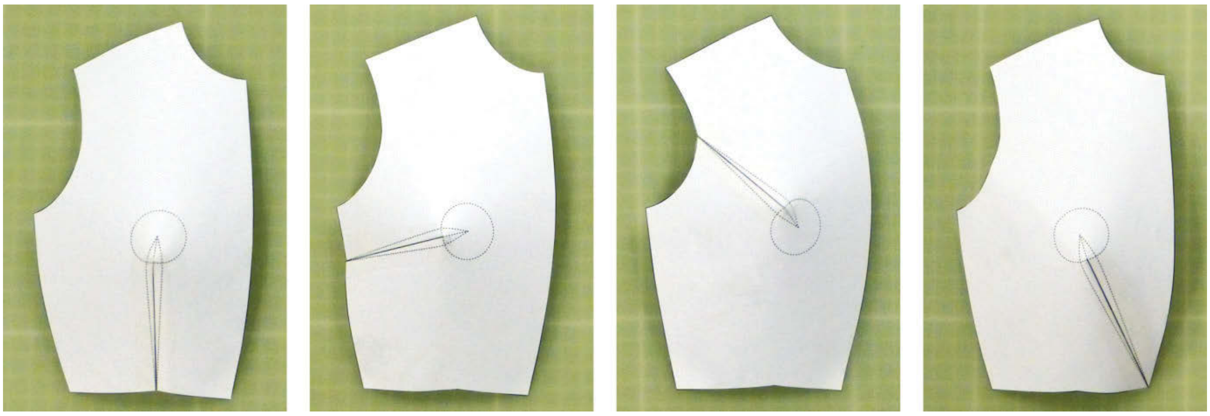
Figure 4: Bust point dart manipulation.

Part 2: Measure the dart angles

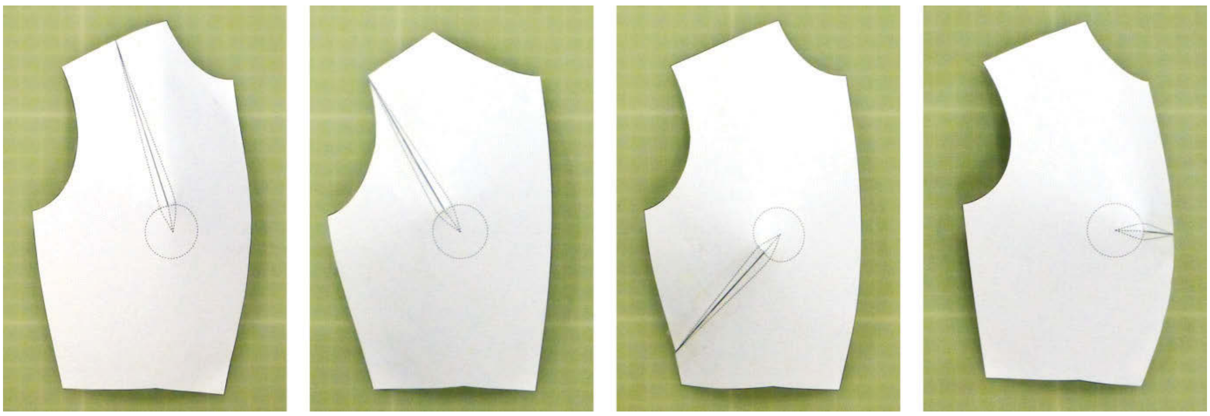


Model 7: Waist Dart.	Model 8: Side seam dart.	Model 9: Armhole dart.	Model 10: Centre front waist dart.	Model 11: Mid-shoulder Dart.	Model 12: Shoulder tip dart.	Model 13: French dart.	Model 14: Centre front dart.

Figure 5: A summary of the darts and their flat patterns created by bust point manipulation.



Model 7: Waist Dart.	Model 8: Side seam dart.	Model 9: Armhole dart.	Model 10: Centre front waist dart.

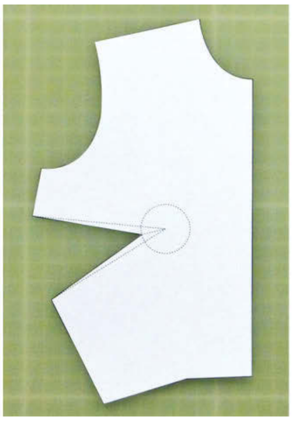


Model 11: Middle-shoulder dart.	Model 12: Shoulder tip dart.	Model 13: French dart.	Model 14: Centre front dart.

Figure 6: A detailed view of patterns with different dart locations created using bust point manipulation.

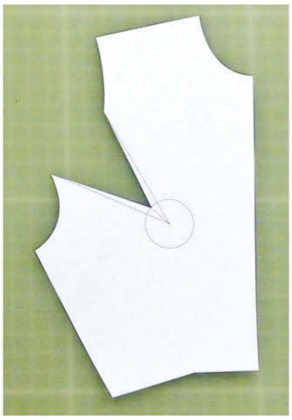
Model 7:

Waist dart.



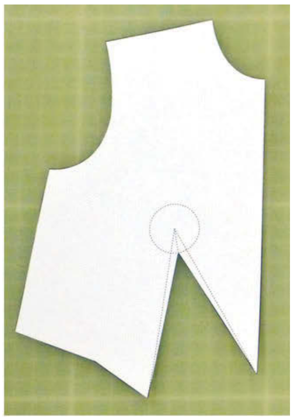
Model 8:

Side seam dart.



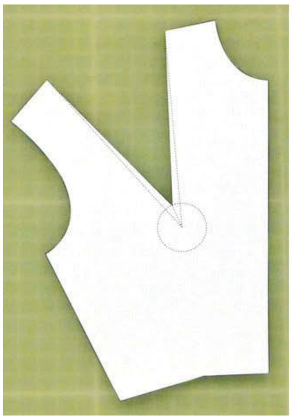
Model 9:

Armhole dart.



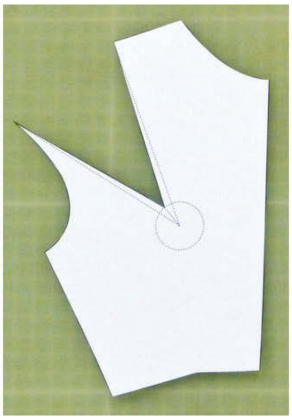
Model 10:

Centre front waist dart.



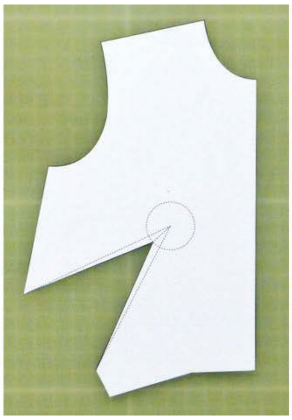
Model 11:

Middle-shoulder Dart.



Model 12:

Shoulder tip dart.



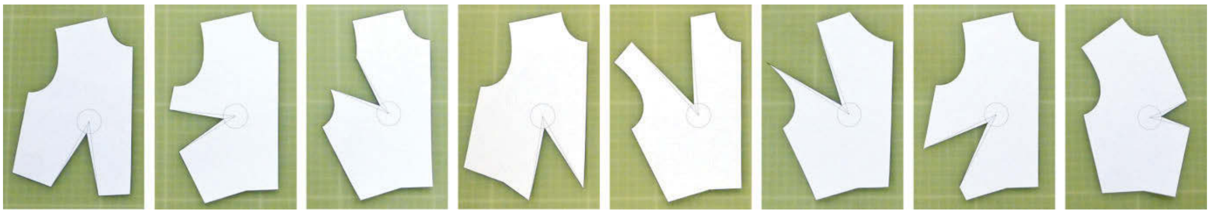
Model 13:

French dart.

Model 14:

Centre front dart.

Figure 7: A detailed view of the flat patterns with different dart locations created using bust point manipulation.

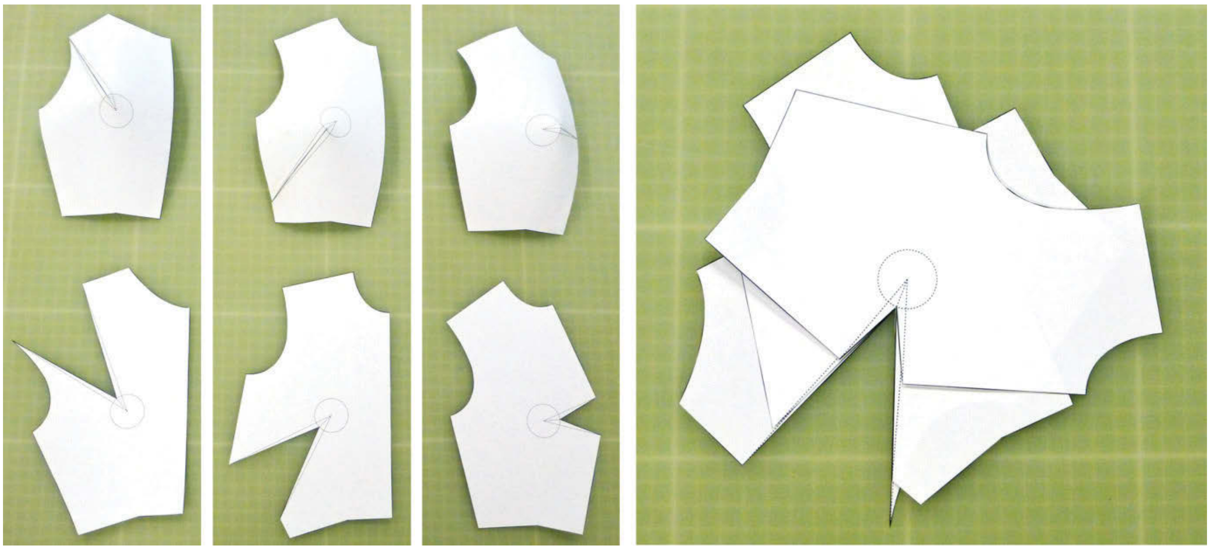


Model 7: Waist Dart:	Model 8: Side seam dart.	Model 9: Armhole dart.	Model 10: Centre front waist dart.	Model 11: Mid-shoulder dart.	Model 12: Shoulder tip dart.	Model 13: French dart.	Model 14: Centre front dart.
Dart angle: 45°	Dart angle: 46°	Dart angle: 46°	Dart angle: 44°	Dart angle: 43°	Dart angle: 42°	Dart angle 44°	Dart angle: 52°
Dart leg length: 6.7 cm	Dart leg length: 5.7 cm	Dart leg length: 5.6 cm	Dart leg length: 7.7cm	Dart leg length: 9.3 cm	Dart leg length: 9.4 cm	Dart leg length: 7.4 cm	Dart leg length: 3.3 cm

Figure 8: Measuring the dart angles in different locations.

Observations

The different models have dart angles of different measurements. Some of them are similar, while model 12 has a dart angle of 42° and model 14 has a dart angle of 52°. This 10° difference is a large amount for a pattern. It can also be observed that model 12 has the longest dart length at 9.3cm while model 14 has the shortest dart length at 3.3cm. These measurements demonstrate that different bust point darts have different dart angles. It can also demonstrate this visually by placing flat patterns on top of each other and looking at their angles. In figure 9 model 12, 8 and 14 are placed on top of each other. Observing the patterns reveals that the darts have different angles.



Model 12: Pattern with shoulder dart.

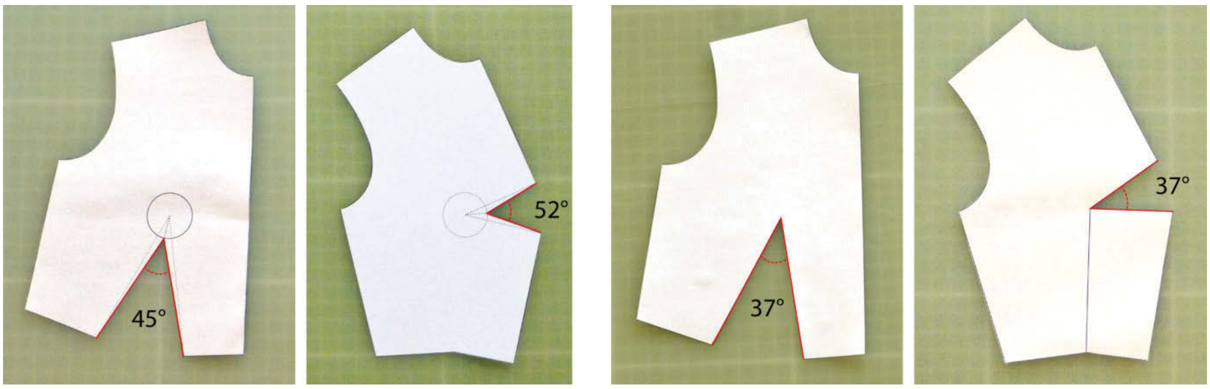
Model 8: Pattern with side seam dart.

Model 14: Pattern with front seam dart.

Aligning the apexes of the darts reveals that the darts have different angles.

Figure 9: Patterns with darts in different locations create different dart angles. This is evident when aligning the dart apexes and comparing the dart angles.

It is also possible to observe that darts that use bust point manipulation create darts of variable sizes. In comparison, darts that maintain the same apex location maintain their dart apex no matter the location of the apex (see figure 10).

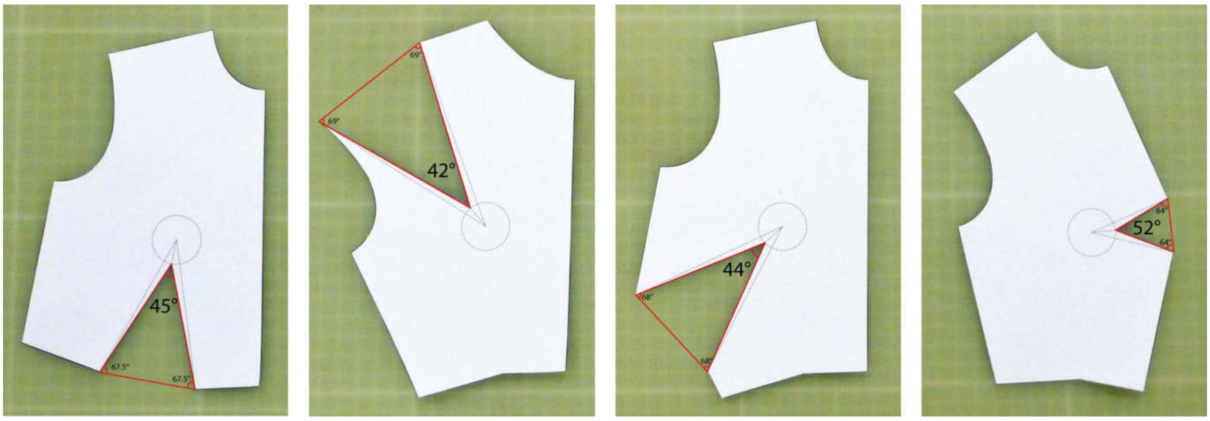


Model 7 and Model 14:
Darts using bust point manipulation technique have different angle sizes.

Patterns with the same apex point:
Darts using dart manipulation centred on bust point have the same angle sizes.

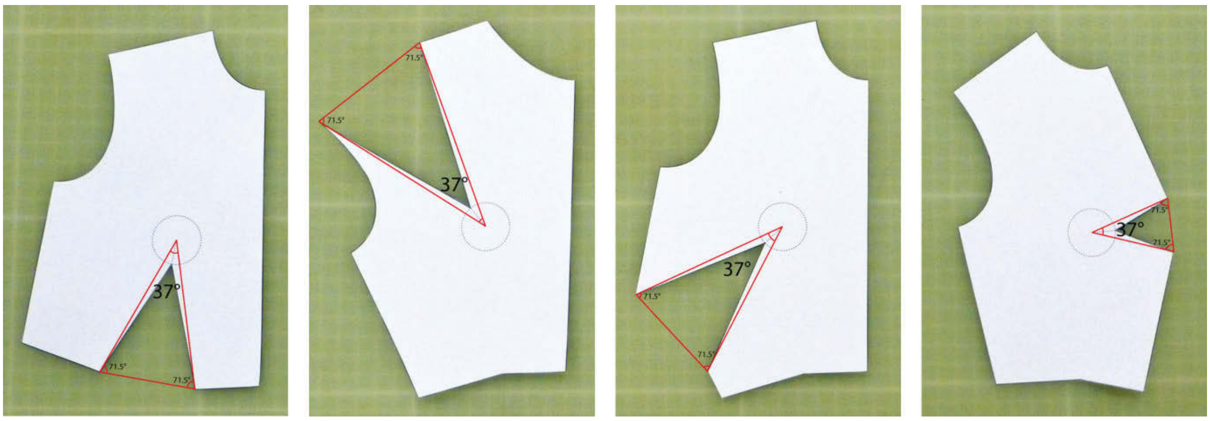
Figure 10: Darts with apex moved in bust point manipulation have different sized angles. Darts pivoted at bust point have the same dart angles.

Following observation of the results, it is possible to draw a triangle around the darts and measure the dart angles of these triangles. Taking model 7, 12, 13 and 14 triangles are drawn between the two dart legs and the apex point. The dart angle of each of these patterns is then recorded (see figure 11). These angles are all different. In comparison, the dart angles at bust point are also measured for each of these models (see figure 12). The dart angles at bust point all remain the same. This supports the idea that moving the location of the dart using bust point dart manipulation changes the angles of the dart.



Model 7 | Model 12 | Model 13 | Model 14

Figure 11: A triangle is drawn on the pattern from the apex of the dart to the edges of the dart legs. These angles are all different.



Model 7 | Model 12 | Model 13 | Model 14

Figure 12: A triangle is drawn on the pattern from the apex at bust point to the dart to the edges of the dart legs. These angles are all the same.

Observations can also be made in relationship to the length of the dart leg and the change in the size of the dart angle. This is demonstrated by comparing the pattern with the tallest dart leg (model 12) to a pattern with a medium dart leg (model 7) and a pattern with the shortest dart leg (model 14). A triangle is drawn on each of the patterns from the apex points to the dart legs to show the angles created by the darts (see figure 13). It is observed that even though the triangle shapes made by the darts are at different heights, the darts are moved the same distance away from bust point. This can be a different ratio to the total height of the triangle (see figure 14). For example, a bust dart with a long dart leg may only move one eighth of its total height, while a short dart leg may move a third of the total height of the dart. This means that moving the bust dart will affect different dart locations in different amounts. The dart length will affect how much the dart leg changes.

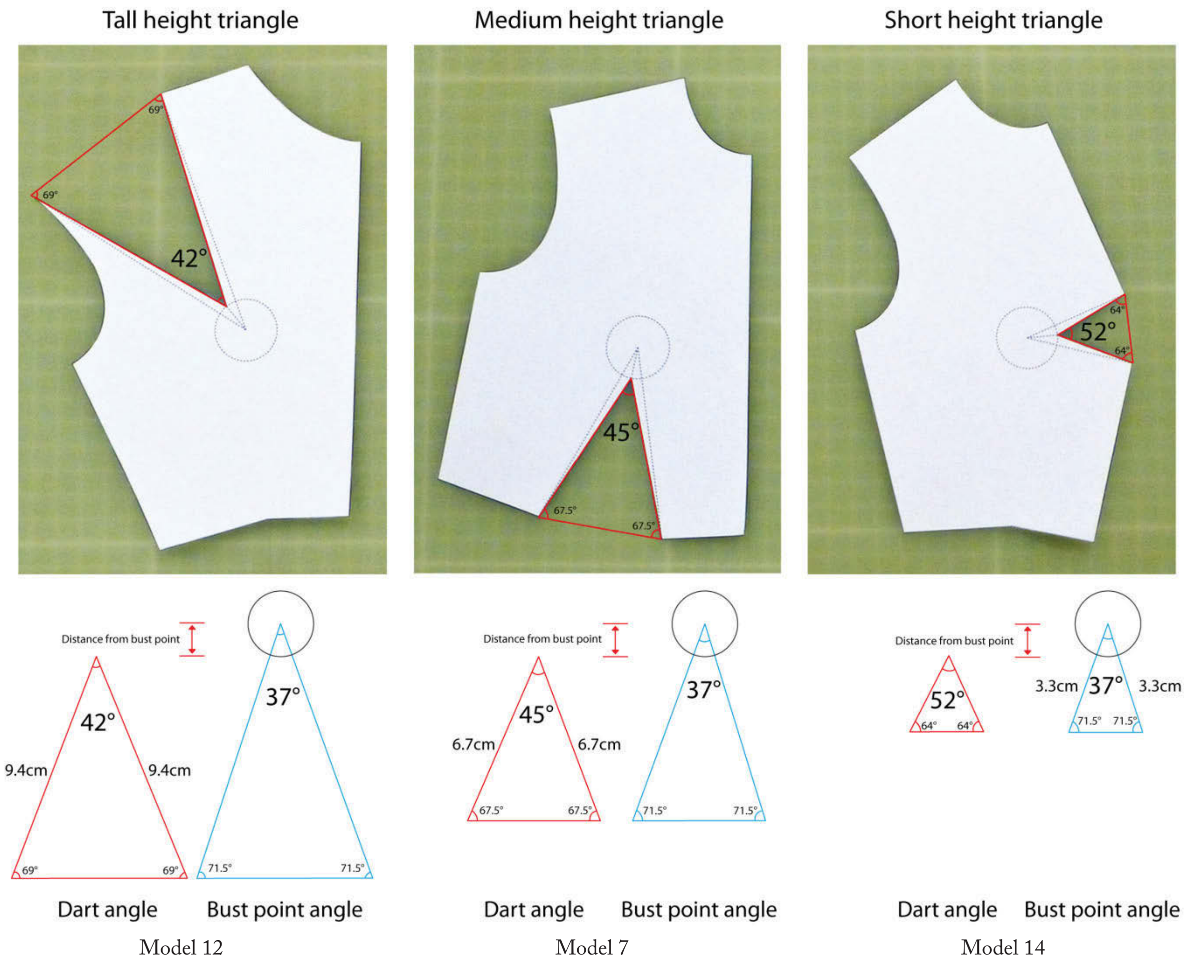


Figure 13: Darts create triangles of different heights.

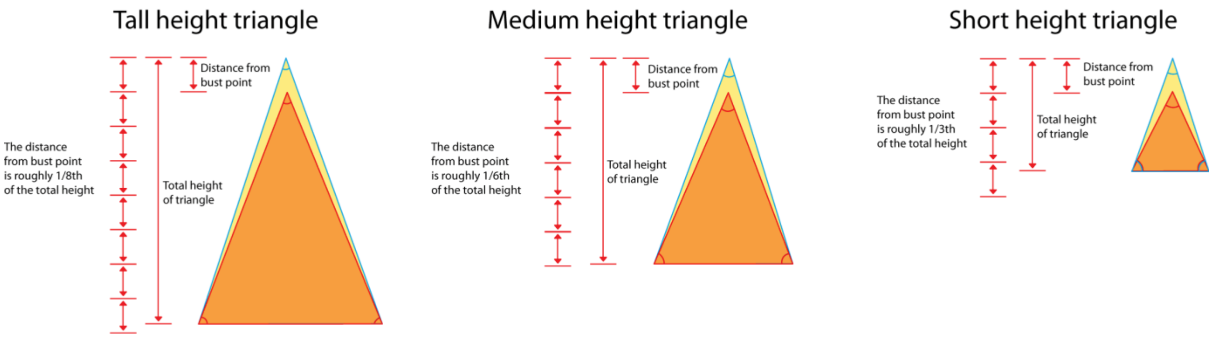
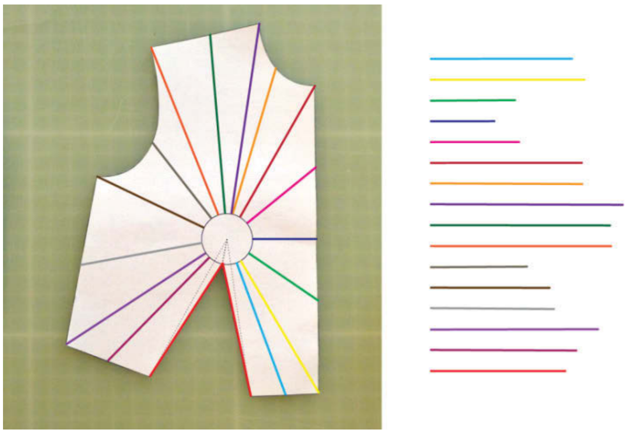


Figure 14: Triangles of different lengths are affected in different ways. When the apex is moved a constant distance in bust point manipulation, this distance is a greater percentage of the triangle's total height. This will change the angle more dramatically.

It is also observed that the location of the dart will affect the length of the dart. To demonstrate the different dart lengths, start with a pattern (model 7) and draw lines from the new dart apex point to different locations on the garment (see figure 15). The lengths of these patterns are then compared. This shows how different dart locations on a pattern can have different lengths, and that these will create dart angles of different sizes. It should be noted that these patterns are third scale patterns. This means that the lengths of the pattern are different, but the geometric relationships between the patterns remain the same.



Different dart locations. Different dart lengths.

Figure 15: The location of the dart will determine the length of the dart leg and the resulting dart angle.

Conclusion

The experiment shows that when bust point dart manipulation is applied to different dart locations, the angle changes. The amount the angle changes is related to the length of the dart leg. Moving the apex of a dart with a different dart leg size changes the size of the angle in differing amounts.

Experiment 21: Surface Area of Traditional Bust Point Dart Manipulation

Rationale

This experiment tests whether changing the dart angle of a pattern will change its surface area. In bust point manipulation the technique is supposed to maintain the same fit as the original garment. To test this idea, it tests the surface area of a pattern before and after bust point manipulation. This is achieved using three-dimensional software 3DS Max (Autodesk 2012), which is capable of measuring the surface areas of patterns. The two-dimensional patterns are entered into the program and the surface areas of the patterns are measured.

Hypothesis

The research anticipates that changing the dart angle will change the surface area of the pattern.

Experimental Design

The experiment measures the surface area of each pattern piece during a bust point manipulation technique. It is able to show whether the transformation maintains the same surface area of the garment. It then compares these results with a dart manipulation where the apex of the dart is not moved. The patterns exists as vector files and are imported into the program 3DS Max (Autodesk 2012), which is capable of measuring the surface area of each pattern (see figure 1). Following this, the results are observed.

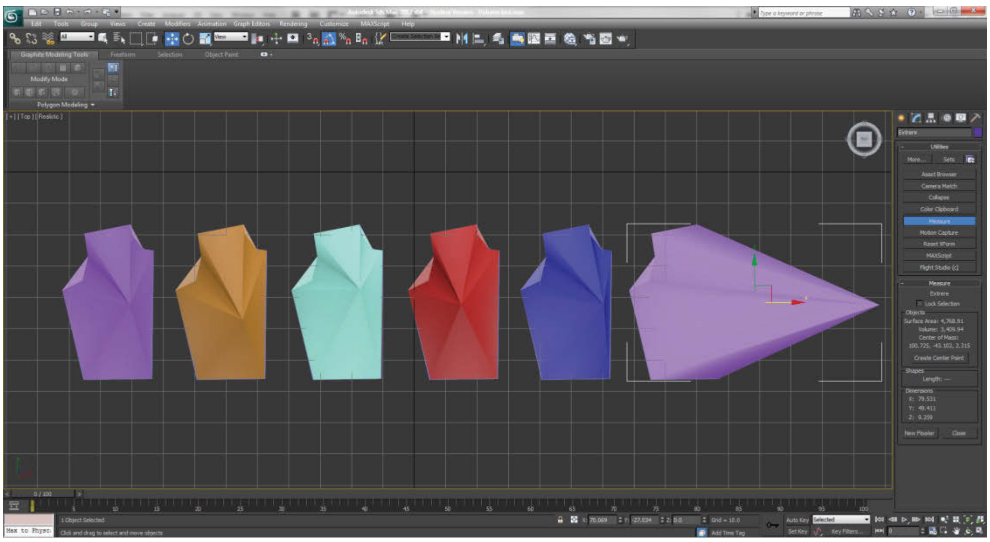


Figure 1: The computer program 3DS Max (Autodesk 2012) measures the surface area of two-dimensional and three-dimensional shapes.

Procedure

The experiment consists of two parts.

Part 1:

The first iteration takes a series of patterns that involve a bust point dart manipulation (see figure 2). These are stored as vector digital files in Adobe Illustrator (Adobe 2015). The patterns are then exported to the program 3DS Max (Autodesk 2012). This program is then used to measure the surface areas of each of these shapes, following which the patterns are observed.

Part 2:

The second iteration takes a series of patterns that involve a dart manipulation on a pattern where the dart apex is not moved (see figure 3). These patterns are then exported from Adobe Illustrator (Adobe 2015) to the program 3DS Max (Autodesk 2012). This program is then used to measure the surface areas of each of these shapes, following which the patterns are observed.

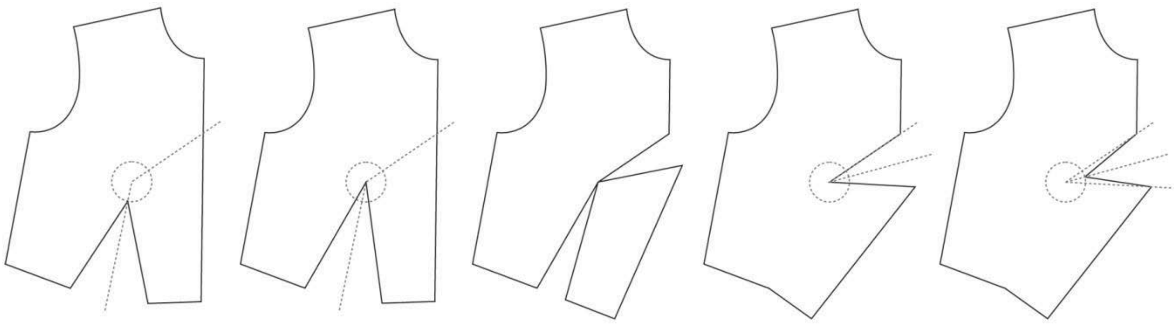
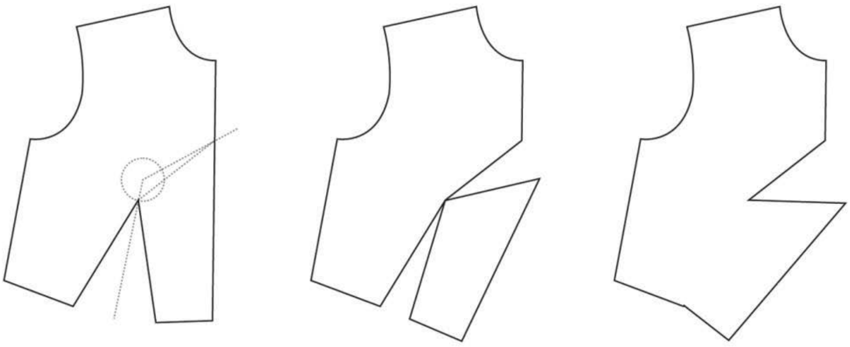


Figure 2: Bust point manipulation created in Adobe illustrator program (Adobe 2015).



Dart with apex away from bust point.

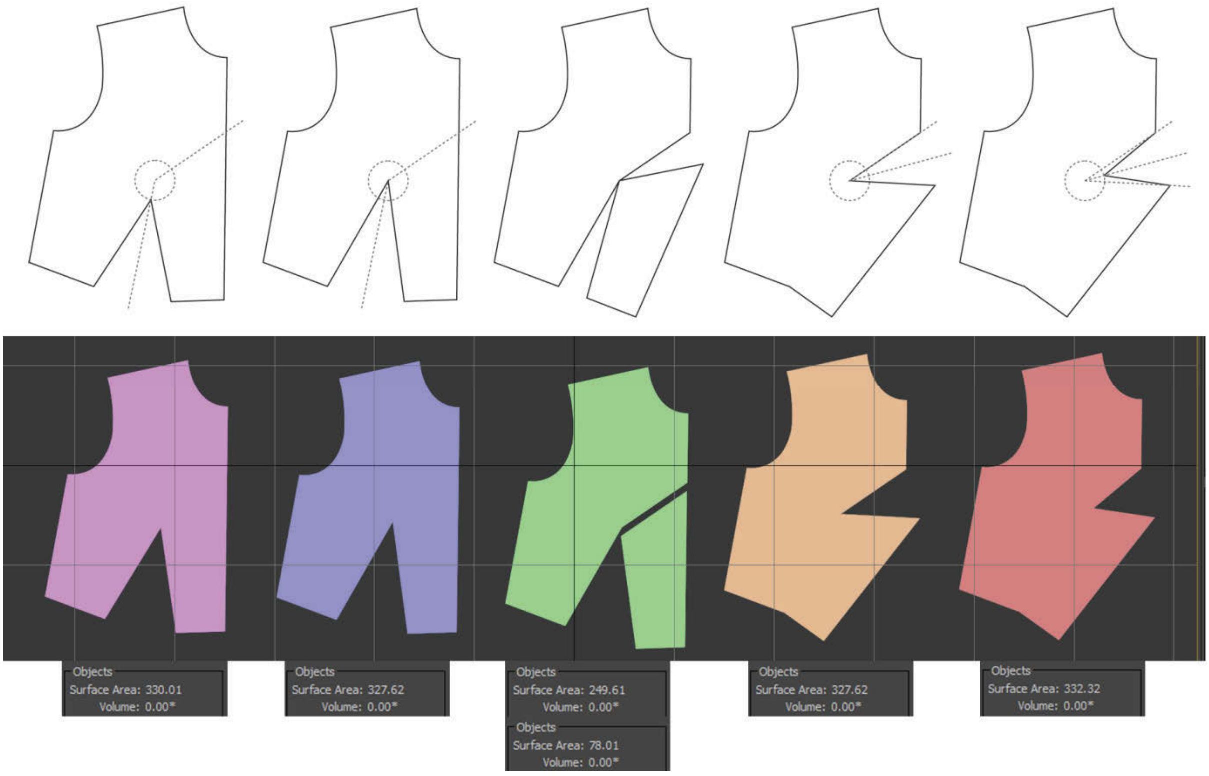
Dart manipulation.

New dart location. The apex is away from bust point.

Figure 3: Applying dart manipulation without moving the location of the apex point.

Results

Part 1:



Model 1: Surface area: 330.01 cm^2

Model 2: Surface area: 327.62 cm^2

Model 3: Surface area: 249.61 + 78.01 = 327.62 cm^2

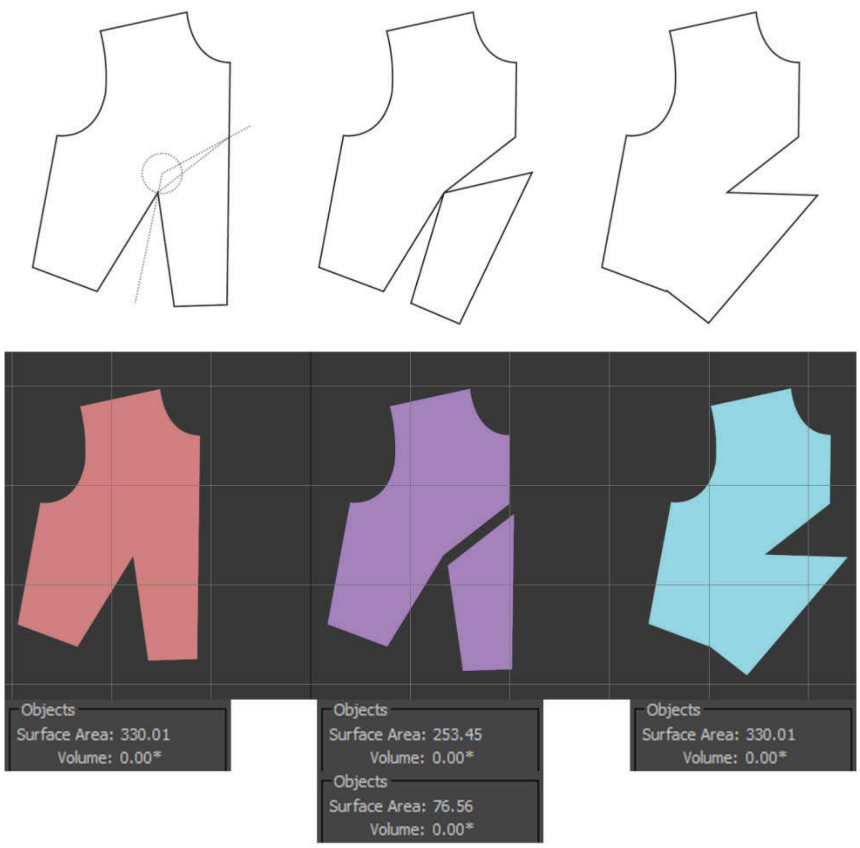
Model 4: Surface area: 327.62 cm^2

Model 5: Surface area: 332.32 cm^2

Figure 4: Patterns digitized in 3DS Max (Autodesk 2012). The surface area of model 1 is different from the surface area of model 5.

In this pattern the initial pattern (model 1) has a different surface area from the final pattern (model 5). This would indicate that they have a slightly different surface area and that they do not have the exact same fit. It is observed that model 1 and model 5 also have slightly different dart angles.

<u>**Part 2**</u>**:**



Model 6:	Model 7:	Model 8:
Surface area:	Surface area: 253.45 + 76.56	Surface area:
330.01 cm^2	= 330.01 cm^2	330.01 cm^2

Figure 5: Measuring the surface area of a pattern when the apex does not move.

Dart manipulation wherein the apex does not move location, maintains the surface area of the original pattern.

Conclusion

When the location of the dart apex is moved, the final pattern has a different surface area from the initial pattern. Moving the apex location changes the dart angle, and this changes the surface area. In the second part of the experiment, the location of the dart apex did not move and the surface area did not change. Maintaining the same apex location and dart angle retains the same surface area in dart manipulations. These results appear to show that bust point manipulation changes the surface area of its pattern and does not allow the exact fit of the garment.

Experiment 22: Using Geometry to Show a Change in Surface Area

Rationale

This experiment seeks to show using geometry that traditional bust point manipulation changes the surface area of a pattern. This is achieved by cutting up two different bust point manipulation patterns and placing them on top of each other. If the surface area is the same, they should perfectly fit on top of each other. If not, then they have different surface areas.

Hypothesis

The research anticipates that the two bust point manipulation patterns will have different surface areas.

Experimental Design

The experiment tests whether patterns that use bust point manipulation techniques have the same surface area. This is done by taking two patterns that have a bust point dart manipulation technique applied to them. The two patterns are cut up and arranged to fit on top of each other. If the patterns have the same surface area they should fit and perfectly align. If not, then they do have the same surface area. The second part of the experiment will apply this approach to a pattern in which the apex point has not been moved.

Procedure

The experiment has two parts. The patterns are recorded as vector files in Adobe illustrator. They are then manipulated and overlapped on each other to compare their surface areas.

Set 1:

Step 1: Start with a garment pattern with a bust point dart that has been manipulated in two different locations.

Step 2: Cut from the edge of the dart legs to the apex point to remove the arrow-shaped wedge out of both of these patterns. This will create two patterns that have darts cut to bust point and two arrow-shaped wedges.

Step 3: Colour the two different sets of patterns in different colours. Cut down the style lines of the garment patterns so that the two patterns resemble each other.

Step 4: Overlap the large pattern pieces on top of each other. They should be the same shape. Overlap the two arrow-shaped wedges on top of each other. They should be a slightly different shape. Make observations of how well these patterns overlap.

Set 2:

Step 1: Start with two identical copies of a garment pattern with bust dart.

Step 2: Use a dart manipulation to move the dart to a new location on the right side of the pattern.

Step 3: Cut these two different dart patterns down their style lines and make the patterns different colours.

Step 4: Overlap the two patterns.

Results

Set 1:

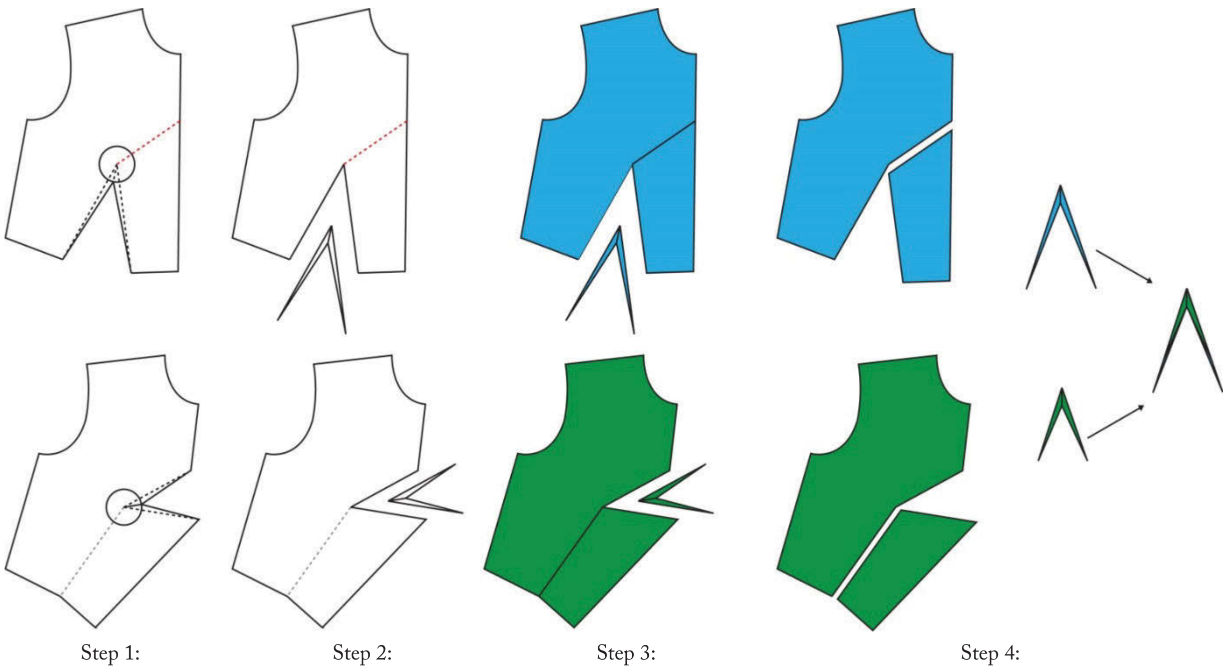
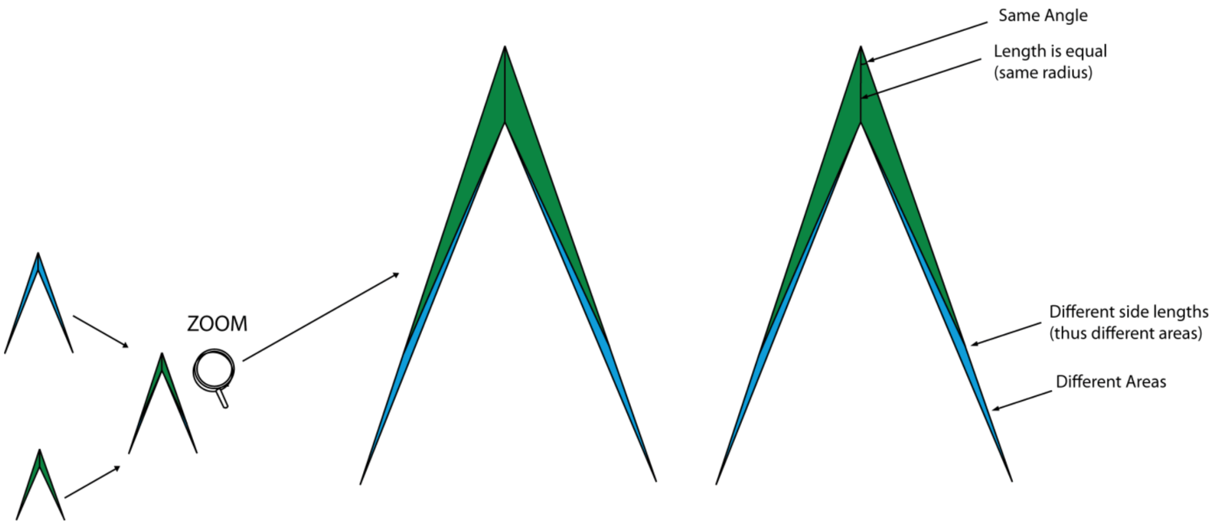
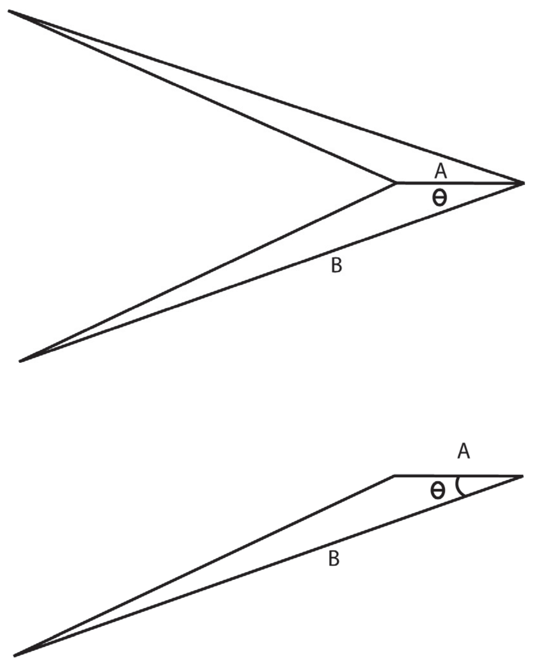


Figure 1: Two patterns created by bust point manipulation are deconstructed into smaller pieces to more accurately measure their surface areas.

Observations





The two triangles are symmetrical.

Side Angle Side. (They share side A, side B is the same and angle θ is the same.)

The area of a triangle is:

Triangle Area = $\frac{1}{2} \times A \times B \times \sin\theta$

Therefore the area of the two triangles is:

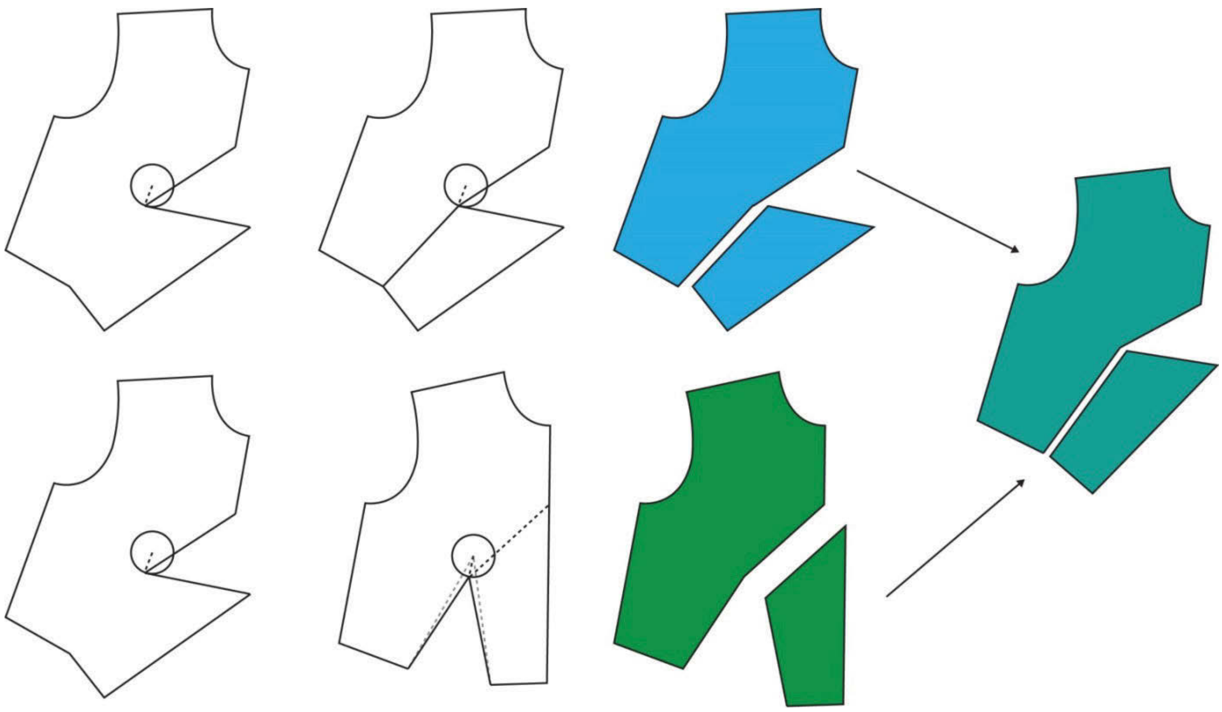
Two Triangles Area = $A \times B \times \sin\theta$

Side A and the angle θ are the same.
So if side B is a different length, then the areas will be different.

Figure 2: The difference in surface area of two darts when the dart apex is moved away from bust point.

Comparing the pattern created by overlapping these patterns shows that they have different surface areas. One of the key differences observed is that the darts have different angles. The dart legs can also be of different lengths. It is observed visually that these patterns do not have the same surface area, so that basic trigonometry can be used to measure the areas of the curves and subtract them from each other.

Set 2:



Step 1:	Step 2:	Step 3:	Step 4:
Start with two identical patterns with dart moved away from bust point.	The top dart remains the same while the bottom dart is manipulated to a new location.	Cut the pattern down the design line and place the patterns on top of each other.	The two patterns overlap and have the same surface area.

Figure 3: Comparing the pattern.

It is observed that these shapes are the same patterns as in the first experiment. The only difference is that they are missing the arrow-shaped wedges that are created by moving the apex of the pattern.

Conclusion

The experiment demonstrates that moving the apex of a dart changes the surface area of a pattern. This means that the original and final patterns do not have the exact same fit.

7. Moving Dart Apexes

Experiment 23: **What happens when we move the apexes of darts**

Experiment 24: **Calculating the tilt of a cone when an apex is moved**

Experiment 25: **Measuring cone tilt at bust point manipulation**

Experiment 26: **The effect of moving apexes of darts**

Experiment 27: **The effect of re-drawing contours, moving the apexes of darts**

Aim

This series of experiments explores what happens when patternmakers move the locations of dart apexes. Moving the apex location of a dart changes its geometric properties. It investigates how moving the dart apexes affects properties such as the cone angle, cone height and tilt of the cone. It is a common practise for patternmakers to re-draw the edges of contoured patterns. It therefore examines how re-drawing a contoured garment can have the same effect as moving multiple apexes.

Method

The first experiment explores how moving the apex of a dart affects the cone angle, cone height and the cone's angle of tilt. The second experiment uses trigonometry to show the angle at which the cone tilts when the location of the apex is moved. The third experiment measures how changing the dart angle when using the bust point manipulation technique can change the cone tilt of the garment. The fourth experiment examines how moving the dart apex towards, beyond, to the left and to the right changes the properties of the dart. The final test makes observations about a technique commonly used by patternmakers that requires re-drawing the contours of patterns.

Analysis

This group of experiments reveals many of the fundamental geometric properties of darts. Darts that are moved create a type called an "oblique cone" and tilt at an angle. An oblique cone is like a small right-angled cone attached to a large crescent-shaped base that tilts the entire angle of the cone. The geometry of oblique cones demonstrates (using trigonometry) that if the dart angle changes, the tilt angle of the cone will also change. This geometric principle can be observed when measuring patterns created using the traditional bust point manipulation technique. Such patterns create cones with different dart angles leading to different tilt angles.

Further, it explores the properties of darts wherein the apex is moved and the darts are moved in different locations. To move the dart beyond the original position decreases the dart angle, while to move it away increases the angle. Again, moving the apex to the left or right decreases the dart angle, as well as making the dart pattern asymmetrical. Finally, it shows the technique of re-drawing contour patterns by blending or truing a pattern to alter the shape of the garment. While these processes are supposed to make the pattern easier to construct, in doing so they move the location of many apex points. Indeed, they often add many apex points and change the shape of the original pattern, so that patternmakers should be aware of exactly how much they are changing the garment shape when they re-draw contours.

Experiment 23: What Happens When we Move the Apexes of Darts

Rationale

This experiment explores what happens to the structure and function of a pattern when the apex of a dart is moved. This is tested by using a series of paper models and observing their properties.

Hypothesis

The research anticipates that moving the apex point of the cone will change the properties of the dart. Some of these changes include changing the dart angle, surface area and cone height.

Experimental Design

The experiment tests how moving the apex location of the dart apex will change different parts of a cone. The first part measures how moving the dart apex changes the dart angle of the cone and the cone's height. The second part observes how the cone is tilted when an apex is moving and how it changes the geometric properties.

Procedure

It shows how moving the apex point of the pattern changes the geometric properties of a dart. It tests two cones with different darts. A cone with the dart at the centre of the cone is referred to as "Cone 1". A second cone with the dart apex moved away from the cone's centre is referred to as "Cone 2".

Part 1: The properties of cones with a moved apex

Set 1: Create two copies of a cone with a dart at the centre of the cone. These cones are referred to as "Cone 1". Leave one cone as a flat pattern and construct the second one in 3D.

Set 2: Create two copies of a cone with a dart moved away from the centre of the cone. These cones are referred to as "Cone 2". Leave one cone as a flat pattern and construct the second one in 3D.

Set 3: Measure the dart angles of cone 1 compared to cone 2.

Set 4: Put cone 1 next to cone 2 and compare the heights of the different cones.

Make observations about the size and shapes of the cones.

Part 2: Observing the tilt of a cone

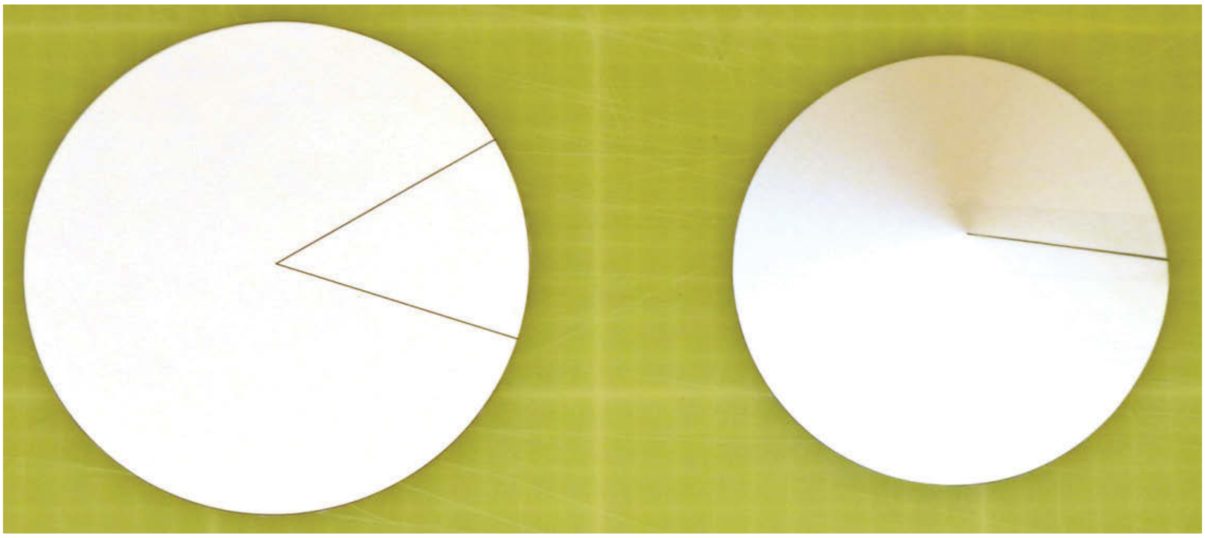
Set 5: Take a cone with the apex moved away from bust point (cone 2). Using a compass centred at the dart apex, draw a circle from the edge of the pattern around the pattern. Shade the remaining crescent-shaped pattern. This creates a right cone mounted on a tilted oblique cone. Construct this pattern in 3D and leave a version as a flat pattern.

Make observations about this new tilted cone pattern.

Results

Part 1: The properties of cones with a moved apex

Set1:

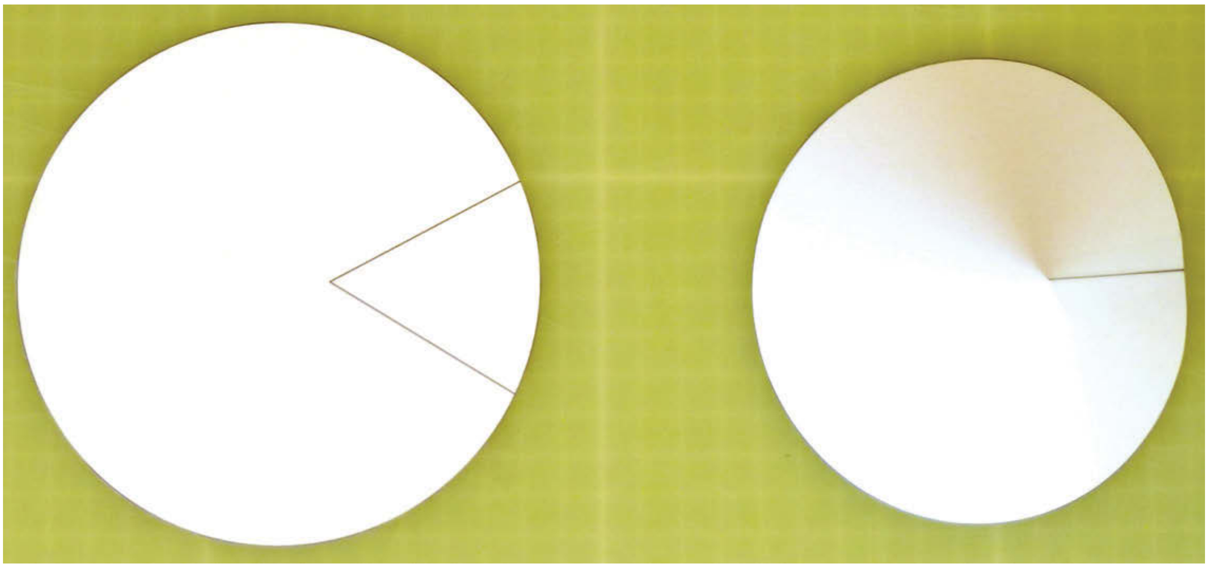


Flat pattern — Cone 1

3D — Cone 1

Figure 1: Cone 1 has a dart apex at the centre of the circle.

Set 2:



Flat pattern

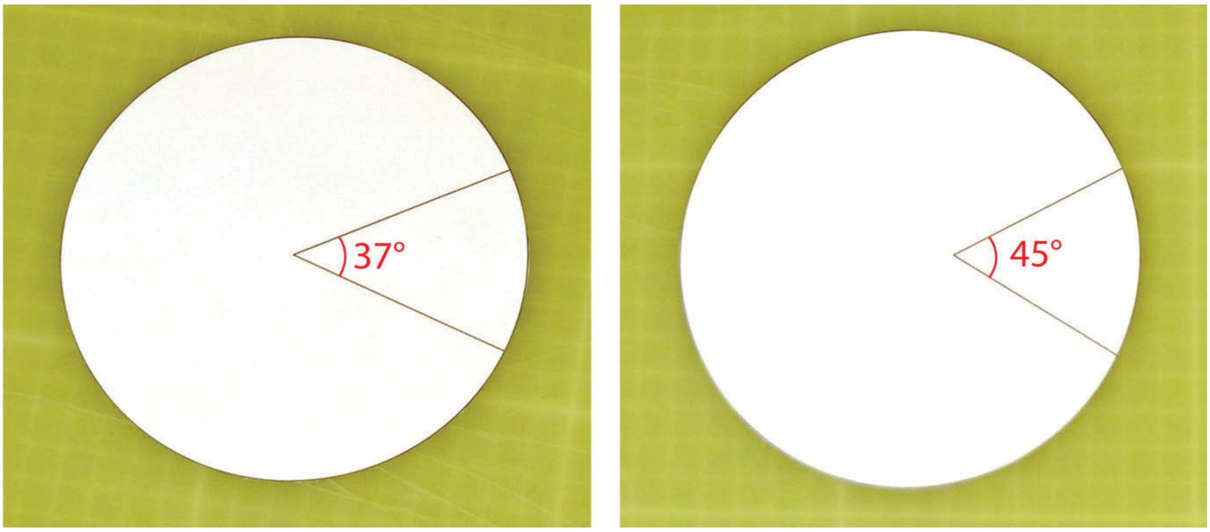
Cone 2

3D

Cone 2

Figure 2: Cone 2 has a dart moved away from the centre of the cone.

Set 3:



Cone 1:

Cone angle is 37°.

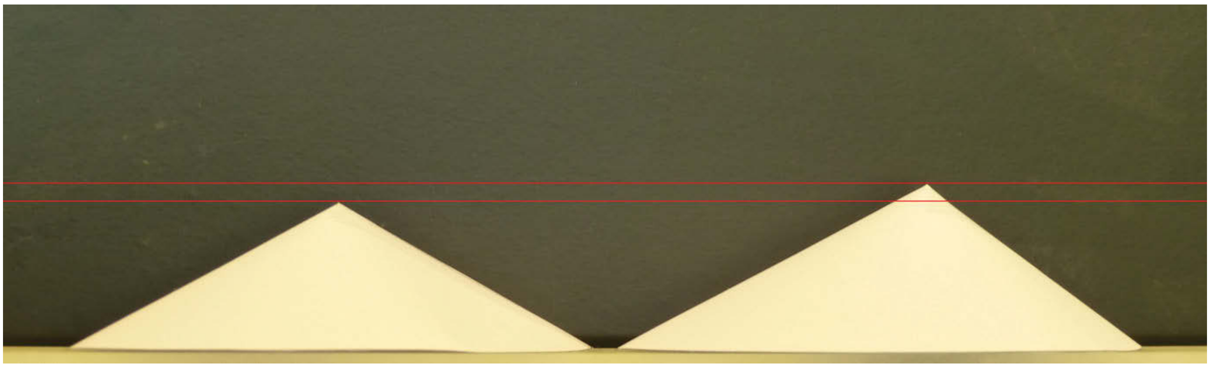
Cone 2:

Cone angle is 45°.

Figure 3: Cone 1 has a smaller angle and longer dart legs. Cone 2 has a larger angle and shorter dart legs.

The cones have different dart angles. Cone 1 has a smaller angle than cone 2.

Set 4:

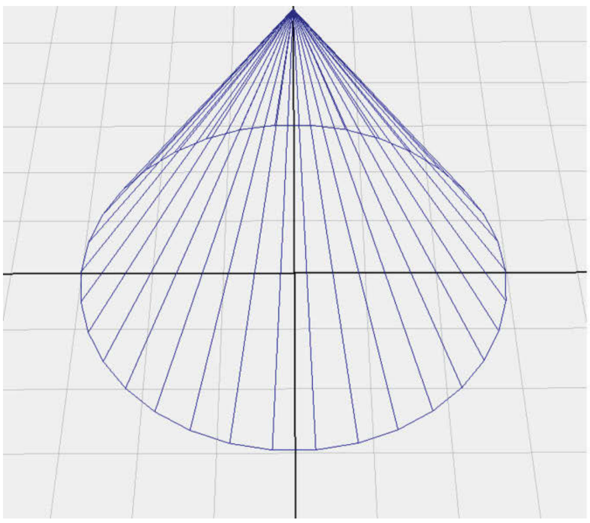


Cone 1 Cone 2

Figure 4: Cone 2 is taller than cone 1.

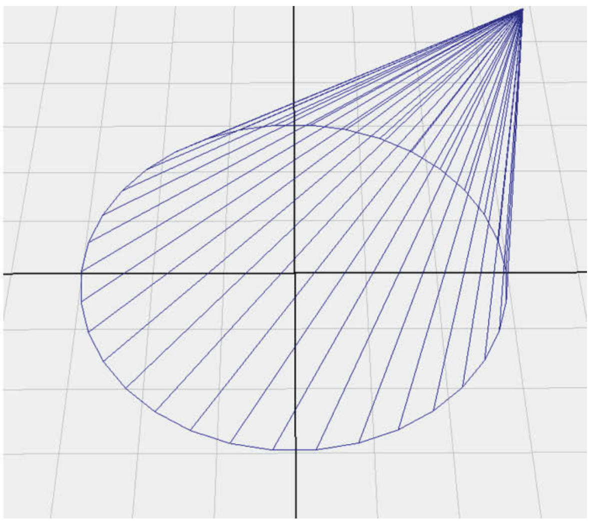
<u>**Observations**</u>**: From Sets 1 -4**

Cone 2 is now taller than cone 1. It also appears that moving the apex of the cone changes its shape. From a geometric point of view cone 2 no longer resembles a right-angled cone, and starts to resemble an oblique cone (see figure 5). Right cones have the tip centred on the cone, while oblique cones have the tip tilted and moved away from the centre. Thereby, to move the apex of the cone does not merely change the dart angle of the cone, but also the type of cone.



Cone 1 is a right cone.

The vertex of the cone is above the centre of the cone.



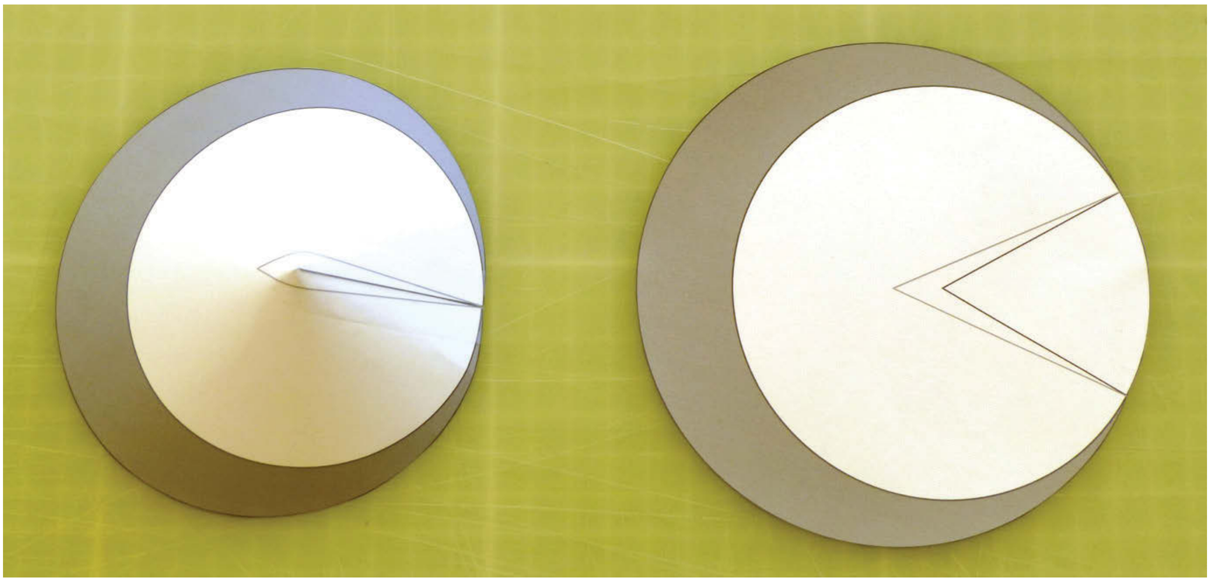
Cone 2 is an oblique cone.

The vertex of the cone is not above the centre of the cone.

Figure 5: Cone 1 is a right cone while cone 2 is an oblique cone.

Part 2: Observing the tilt of a cone

Set 5:



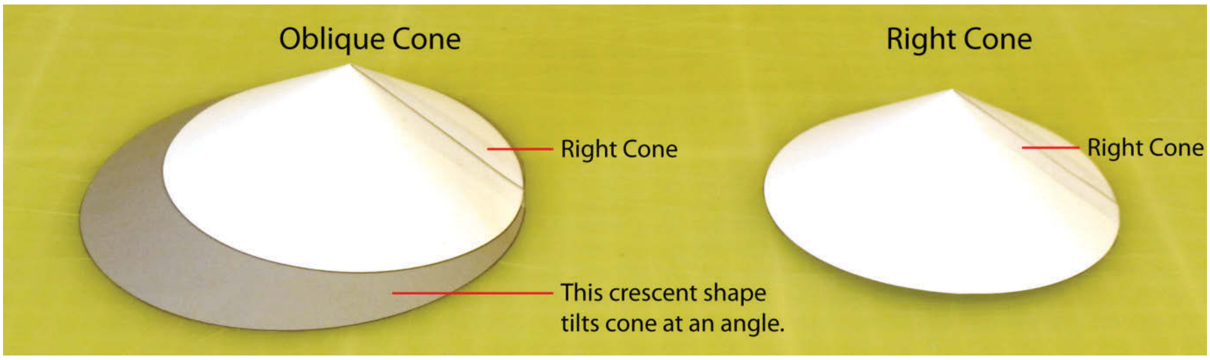
3D
An oblique cone with a circle drawn around the dart.

Flat
An oblique cone with a circle drawn around the dart.

Figure 6: Drawing a circle centred on the apex point creates a right cone mounted on an oblique cone.

Observations: From Set 5

Drawing a circle around the apex of the dart reveals that the cone has the properties of a smaller right-angled cone mounted on a tilted crescent shape. Moving the apex of the dart changes the size of the cone, making the dart angle greater and the cone taller. The cone is also tilted on an angle determined by the crescent shape in the pattern (see figure 7). Moving the location of the apex transforms a cone from a right cone into an oblique one. This dramatically changes its structure and tilts its direction.



The oblique cone. This right cone is cut off the top of the oblique cone.

Figure 7: The dart is off centred from the original dart, take a compass and draw a circle around the radius of the bust dart.

Conclusion

The experiment demonstrates that moving the apex of a dart has a dramatic effect on the structure and function of a cone. It changes the cone's dart angle, making it taller, as well as transforming the cone from a right-angled to an oblique one. This tilts the angle of the cone and changes its geometric properties.

Experiment 24: Calculating the Tilt of a Cone when an Apex is Moved

Rationale

The aim of this experiment is to find the mathematical formula to calculate the tilt angle created by a cone when a dart apex point is moved. Moving a dart apex changes the dart angle and the geometric properties of a cone. By making observations and manipulating the mathematical formulae of cones it may be possible to find a mathematical equation that correlates the change in the apex to the tilt of the cone angle.

Hypothesis

The research anticipates that it should be possible to work out a mathematical relationship between the dart angle and the tilt of the cone.

Experimental Design

This experiment is designed to find a mathematical relationship between moving the dart apex and the amount that the cone tilts. The first part observes how moving the apex location of the dart changes the cone's properties. The second part uses these observations to establish a mathematical formula that describes this relationship. The goal is to find the mathematical relationship between the dart angles, and to what extent the cone angle tilts.

Procedure

The experiment consists of two parts.

<u>Part 1:</u>

First observe what happens when the dart apex is moved and how this affects the tilt of a cone. It begins with a block garment pattern and a dart that has been moved away from the apex point. A circle is drawn centred on the dart apex.

Set 1:

Model 1: Start with a basic block pattern with a dart at bust point (the dart drawn in red). Draw a circle centred on bust point to the edge of the pattern. Then move the apex point away from bust point and draw a new dart in black. Draw a circle centred on the bust point to the edge of the pattern. Shade the crescent shape between these patterns.

Model 2: Create and identical copy of model 1, then cut the circular cone shape out of the pattern. This reveals a right-angle cone on top of a tilted oblique cone shaded in grey.

Model 3: Recreate model 1 and construct the pattern in 3D.

Model 4: Recreate model 2 and construct in 3D.

Observe these patterns.

Set 2:

This iteration tests a variation of the first experiment, which draws a cone that fits within the pattern. However, this is dependent on the length of the dart leg, and not all cone patterns fit neatly within the pattern. This makes it difficult to observe how the pattern tilts the cone. Drawing a large circle outside the pattern helps to remedy the situation. This time, draw two large circles outside the patterns that are centred on the bust point and the location of the moved dart apex. The two circles create a crescent shape that shows how the pattern tilts.

Model 5: Start with a block pattern with a dart angle. Draw a circle around the outside of the pattern. Draw another circle on the outside of the pattern with an additional length of 0.8 cm. Shade the region between the two patterns grey.

Model 6: Recreate model 5. This time move the apex 0.8 cm away from bust point and draw a circle centred on the dart apex point. Shade the region between the two patterns grey.

Model 7: Recreate model 5 and construct in 3D.

Model 8: Recreate model 6 and construct in 3D.

Make observations of these models.

Part 2:

The second part of the experiment makes observations about the aforementioned paper models and uses geometry to calculate a relationship between the change of cone angle and the cone's tilt.

Make observations about model 2 and model 4. Look at the structure of this pattern and use geometry to find a trigonometric relationship between the dart angle of the pattern and the tilt of the cone.

Diagram 1: This depicts model 4, identifying the top cone angle and the tilt angle. The crescent shape that tilts the right cone is also shaded in grey. The right-angle triangle of the right cone is shaded in blue.

Diagram 2: This depicts model 2, identifying the dart angle of the pattern. The diagram has a circle centred at dart point and shades the outside crescent shape of the pattern in grey.

Diagram 3: This takes diagram 1 and mounts it on top of a larger cone, which has the same cone angle as the original pattern but with a radius the same length as the long edge of the pattern in diagram 1.

Diagram 4: Cut diagram 3 in half to create a cross-section. This makes it easier to calculate the angles and lengths of the different measurements.

Diagram 5: This is a mathematical representation of the cross-section in diagram 4. It shows important lengths such as the tilt angle, slant length, base length of the slanted cone, base length and cone angle. Using trigonometry it is possible to calculate a mathematical relationship between the tilt length and the dart angle of the cone.

Diagram 6: Start with diagram 5. Call the tilt angle of the cone angle *gamma* or the symbol "γ". According to trigonometry, the tilt angle of the cone is equal to the angle at the base of the cone. This is because the base lengths of the cone are parallel and alternate angles are equal.

In order to calculate the length of the tilt angle, other measurements need to be calculated. These include the measurements shown in diagrams 7, 8, 9 and 10. These include:

Diagram 7: Base of the cone or theta (θ).
Diagram 8: Base length of the slanted cone or "c".
Diagram 9: Slant length "a".
Diagram 10: Base length "b".

In order to physically measure length "a" and "b" see:

Diagram 11: To measure slant length "a".

Diagram 12: To measure base length “b”.

Diagram 13: The length of side “c” needs to be calculated in order to work out the tilt angle of the cone. This diagram shows side “c” in red.

Diagram 14: According to the law of cosines, sides “a” (slant length), “b” (base length) and angle “θ” can be used to calculate side “c” (base of slanted cone).

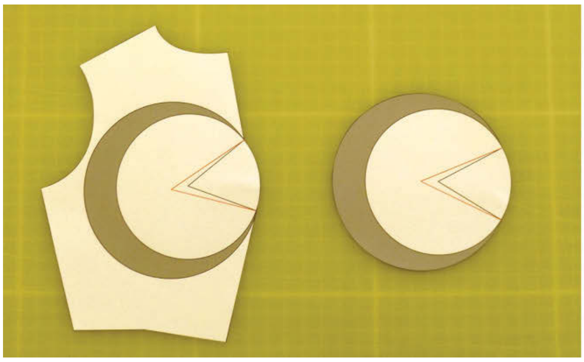
Diagram 15: Using a variation of the law of cosines, it is possible to calculate tilt angle “γ” using the measurements of sides “a” (base of slanted cone), “b” (base length) and “c” (slant length). Please note that for this equation, sides “a” and “c” have been renamed and have switched location.

There is also a relationship between the dart angle of the flat pattern of a cone and the cone angle theta (θ). This creates a relationship between the cone tilt angle and the size of the dart.

Diagram 16: Using the law of cosines it is possible to calculate a relationship between cone angle θ and “D”, the length of the dart leg and the dart angle (ε). This relates the dart angle and length to the cone angle theta (θ). This goes on to affect the cone tilt angle, showing a mathematical relationship between dart size, dart leg length and cone tilt.

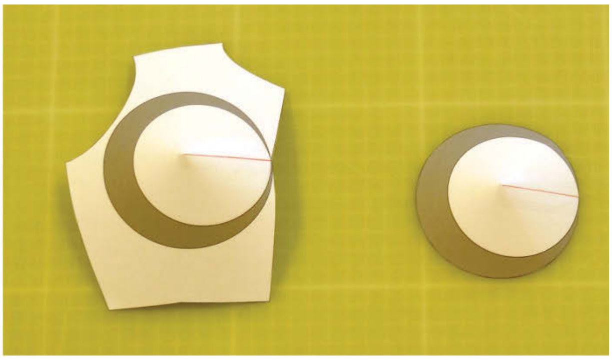
Results

Part 1:



Model 1 and 2:

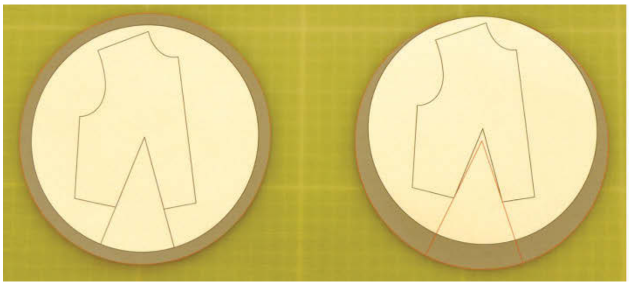
Flat pattern.



Model 3 and 4:

3D pattern.

Figure 1: Moving the location of the dart affects the geometric properties of the pattern. Two circles are drawn around the two apexes. The shaded area shows how the cone is being tilted in a direction.



Model 5 and 6:

Flat pattern.

Model 7 and 8:

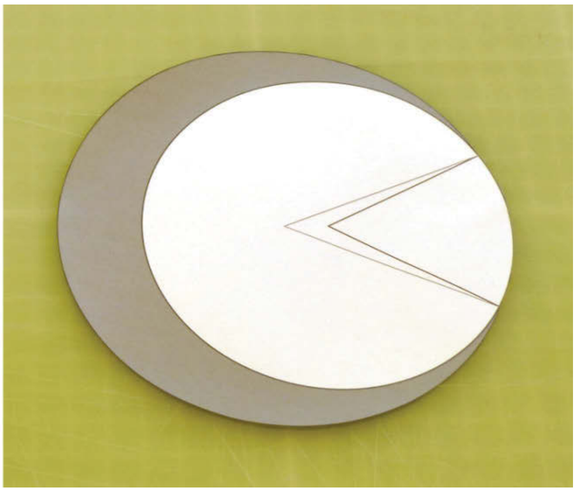
3D pattern.

Figure 2: Drawing two large circles around the apex points of these patterns demonstrates how moving the apex points shifts the position of the cone. The shaded area helps to show how the cone is being tilted.

<u>Part 2</u>:

Model 4:

Flat pattern.



Model 2:

3D pattern.

Figure 3: Two circles are drawn centred on the two different apexes. The shaded area helps to show how the cone is being tilted.

Observations

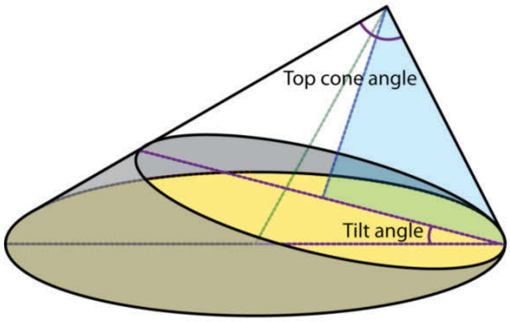


Diagram 1:
A 3D representation of the oblique cone. It should be viewed as a right cone being tilted on angle by a crescent shape.

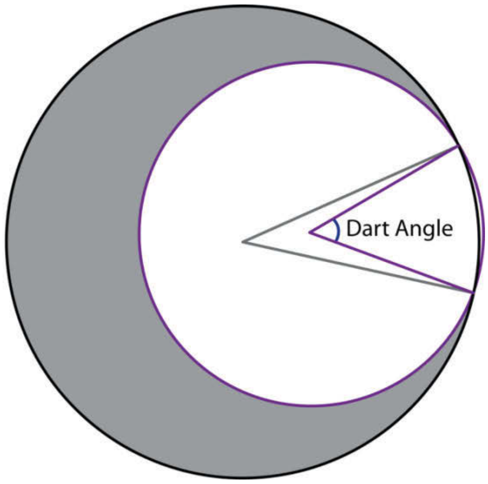


Diagram 2:
A flat pattern of the oblique cone showing. A right cone (in white) mounted on a tilted crescent shape (shaded).

Figure 4: The oblique cone can be seen as a right cone mounted on a tilted crescent shape. This shape tilts the cone at an angle.

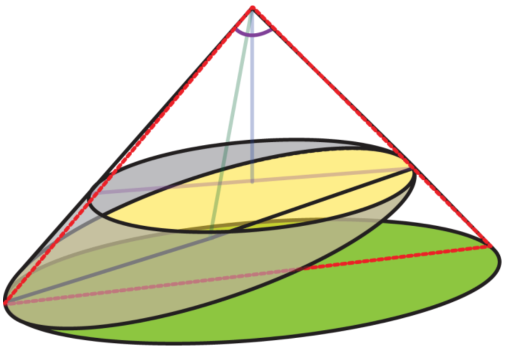


Diagram 3:
The oblique cone is cut in half.

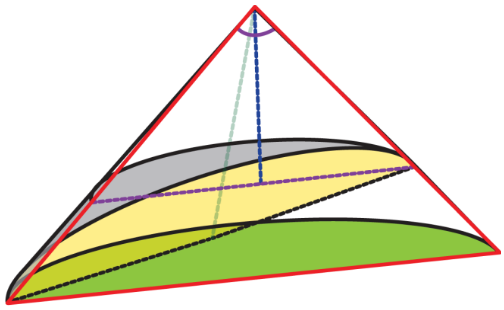


Diagram 4:
Cross-section of the oblique cone.

Figure 5: The oblique cone is cut in half and viewed as a cross-section.

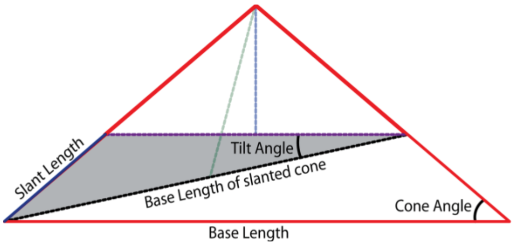


Diagram 5:
Measurements on a
cross-section of the cone.

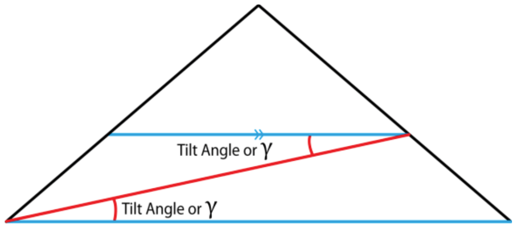


Diagram 6:
The angles are equal because the lines are
parallel with alternate angles.

Figure 6: Analysing measurements on a cross-section of the cone.

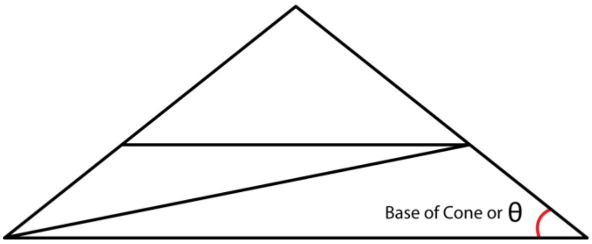


Diagram 7:
Base of cone angle or $'\theta'$.

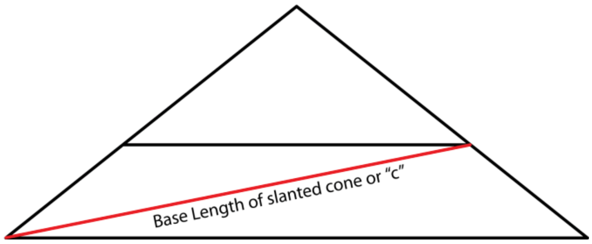


Diagram 8:
Length of slanted cone or "c".

Figure 7: Other measurements need to be found before calculating the tilt angle of the cone.

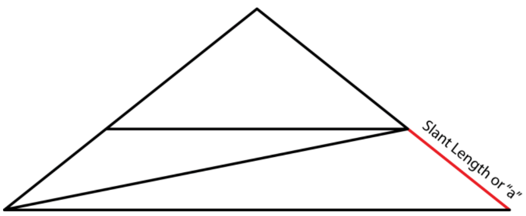


Diagram 9:
Slant length of "a".

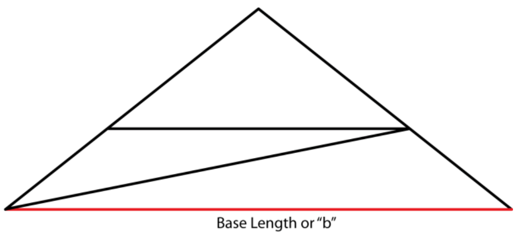


Diagram 10:
Base length of "b".

Figure 8: Measurements that need to be found in order to calculate the slant length of the cone.

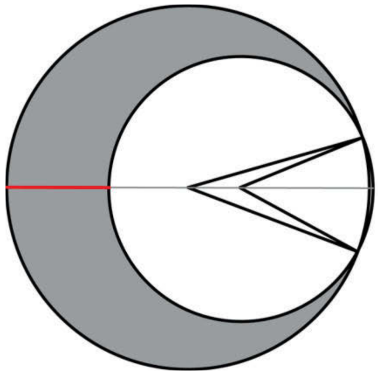


Diagram 11:

Slant length of "a".

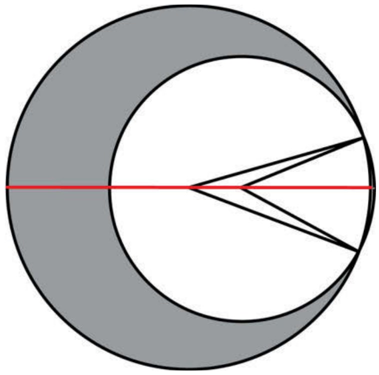


Diagram 12:

Base length of "b".

Figure 9: The measurements of the pattern can be found by measuring the flat pattern.

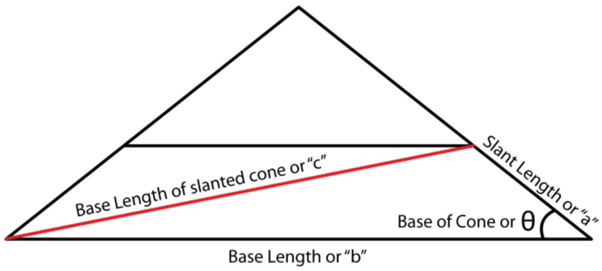


Diagram 13:

Lengths a, b and angle θ are not all known.

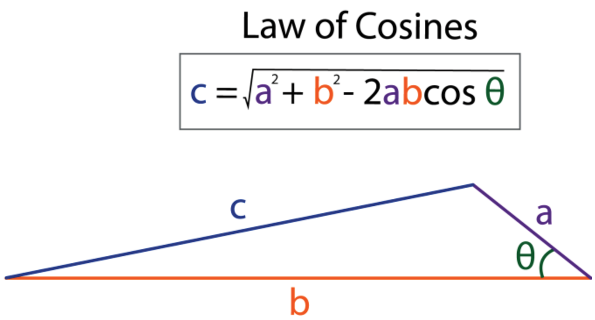
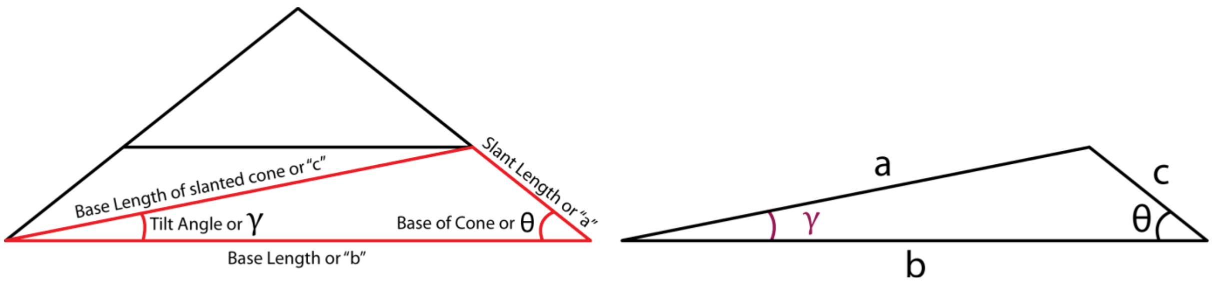


Diagram 14:

Using the law of cosines, it is possible to find length "c", which is the base of the tilted cone.

Figure 10: The measurements that need to be found in order to calculate the slant length of the cone.



To find the tilt angle, use the Law of Cosines:

Variation of the Law of Cosines:

$$c^2 = a^2 + b^2 - 2ab\cos\gamma$$

a = base of slanted cone

b = base length

c = slant length

Therefore:

$$\boxed{\gamma = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right)}$$

Diagram 15

Figure 11: The measurements that need to be found in order to calculate the slant length of the cone.

Finding the angle of the cone base:

$$\cos\theta = \frac{adjacent}{hypotenuse}$$

$$\theta = \cos^{-1}\left(\frac{adjacent}{hypotenuse}\right)$$

The hypotenuse side is S on the cone which is D on the flat pattern.

The adjacent side R can be calculated from the dart leg (D) and the cone angle (ε).

To find side R find the circumferences of the base of the cone:

$$C = 2\pi R$$

$$\therefore R = \frac{C}{2\pi}$$

To find the circumference of the base as a ratio of dart length and dart angle:

$$C = 2\pi D \times \left(\frac{360° - \varepsilon}{360°}\right)$$

Combine the two equations:

$$R = \frac{2\pi D \times \left(\frac{360° - \varepsilon}{360°}\right)}{2\pi}$$

$$\therefore R = \left(\frac{360° - \varepsilon}{360°}\right) \times D$$

Use side R to calculate the cone angle θ.

$$\theta = \cos^{-1}\left(\frac{\left(\frac{360° - \varepsilon}{360°}\right) \times D}{D}\right)$$

$$\boxed{\theta = \cos^{-1}\left(\frac{360° - \varepsilon}{360°}\right)}$$

This formula only requires us to know the dart angle ε and dart leg D to find angle θ.

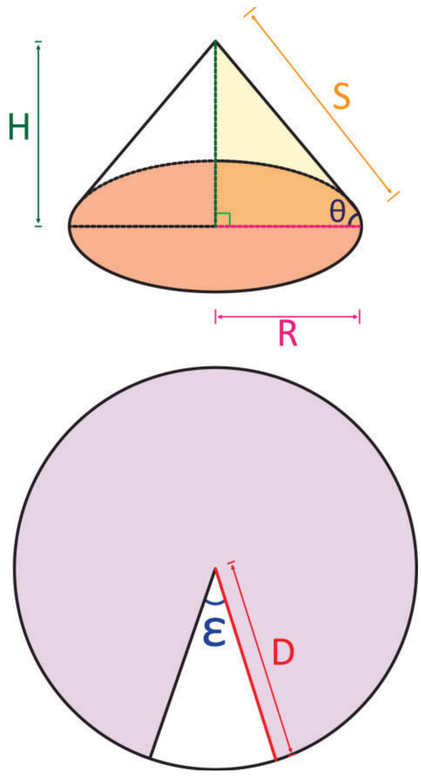


Diagram 16

Figure 12: Finding the angle of the base of the cone, using the length of the dart leg and the dart angle.

Conclusion

The research has demonstrated that changing the angle of a dart tilts the cone at a different angle. There is a mathematical relationship between the tilt angle of the cone and the angle of the dart.

Experiment 25: Measuring Cone Tilt at Bust Point Manipulation

Rationale

This experiment observes how bust point manipulation creates patterns with different dart angles, and how this changes the pattern's geometric properties. It measures how changing the cone angle of a dart tilts the cone at an angle, and examines how this creates the effect of an oblique cone.

Hypothesis

The research anticipates that moving the apex point of a cone changes its cone angle and tilts the direction of the cone.

Experimental Design

The experiment takes three bust point manipulation patterns from different locations. They have different dart leg lengths and dart angles. The patterns then have circles drawn around their apex points. Next, draw a second circle with an apex at bust point that intersects with the edges of the darts. This helps to show how moving the dart apex has tilted the cone and made it more oblique in shape. Then measure the tilt of this top cone using a protractor.

Procedure

The experiment takes three basic blocks with darts, and makes bust point manipulations in different locations. Each pattern has an apex point in a different location, a dart of a different angle and a dart leg of a different length.

Model 1: Use bust point manipulation to create a dart at the waist of a block pattern.

Model 2: Use bust point manipulation to create a pattern with a dart at the shoulder of the pattern.

Model 3: Use bust point manipulation to create a dart on the centre front of the garment.

Measure the dart angle and dart leg length of each of these patterns.

Model 4: Draft model 1 on paper. Using a compass, draw a circle centred on the apex point to the edge of the dart. Draw another circle centred on bust point to the edge of the dart. Cut around the outside of the pattern including the circle. Construct the pattern in 3D.

Model 5: Draft model 2 on paper. Using a compass, draw a circle centred on the apex point to the edge of the dart. Draw another circle centred on bust point to the edge of the dart. Cut around the outside of the pattern including the circle. Construct the pattern in 3D.

Model 6: Draft model 3 on paper. Using a compass, draw a circle centred on the apex point to the edge of the dart. Draw another circle centred on bust point to the edge of the dart. Cut around the outside of the pattern including the circle. Construct the pattern in 3D.

Model 7: Recreate model 4 and flatten the pattern.

Model 8: Recreate model 5 and flatten the pattern.

Model 9: Recreate model 6 and flatten the pattern.

Model 10: Recreate model 4 and cut the cone shape out of the pattern.

Model 11: Recreate model 5 and cut the cone shape out of the pattern.

Model 12: Recreate model 6 and cut the cone shape out of the pattern.

Model 13: Recreate model 10 and flatten the pattern.

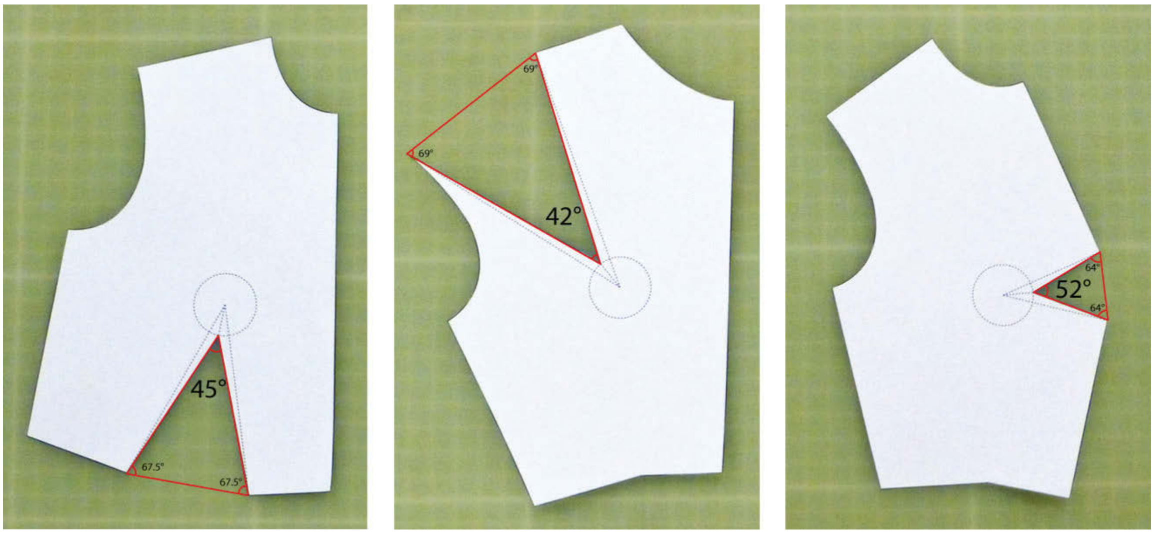
Model 14: Recreate model 11 and flatten the pattern.

Model 15: Recreate model 12 and flatten the pattern.

Make observations of these patterns. Take patterns 10, 11 and 12 and measure the dart angle, dart length and cone tilt of the cone.

Results

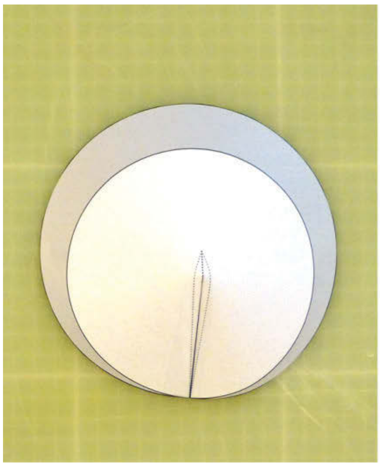
Set 1:



Model 1:	Model 2:	Model 3:
Waist Dart.	Shoulder tip dart.	Centre front dart.
Dart angle: 45°.	Dart angle: 42°.	Dart angle: 52°.
Dart leg length: 6.7 cm	Dart leg length: 9.4 cm	Dart leg length: 3.3 cm

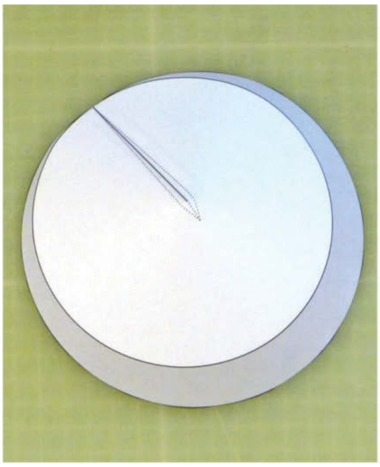
Figure 1: Darts created from bust point manipulation with their darts in different locations.

Figure 2: Circles are drawn around the dart apex and the bust point to show the tilt of the oblique cone of the pattern.



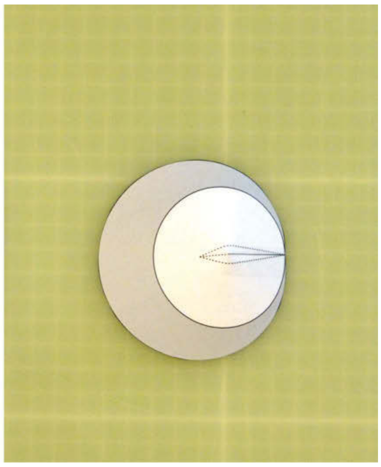
3D

Model 10



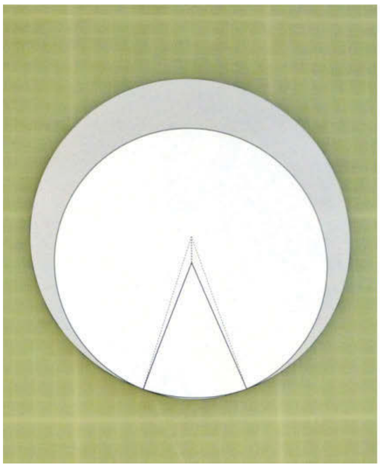
3D

Model 11



3D

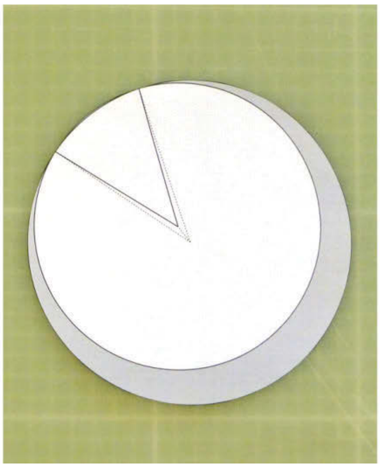
Model 12



Flat

Model 13:

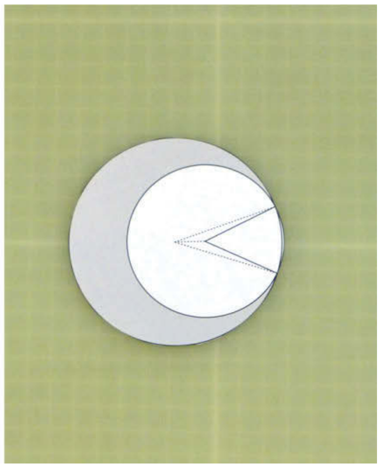
Waist Dart.



Flat

Model 14:

Shoulder tip dart.



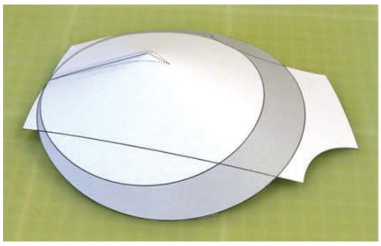
Flat

Model 15:

Centre front dart.

Figure 3: The cones from the pattern pieces are cut out and analysed.

Observations



Cone on pattern

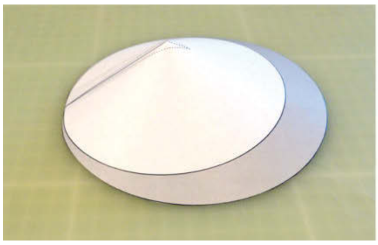
Model 4

Cone on pattern

Model 5

Cone on pattern

Model 6



Cone

Model 10:
Waist dart.

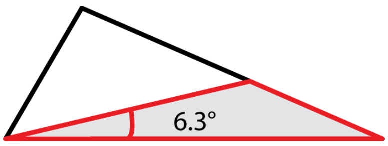
Cone

Model 11:
Shoulder tip dart.

Cone

Model 12:
Centre front dart.

Figure 4: Side view of the pattern and cone tilt created by moving the apex. This shows the different tilt angles of the oblique cone.

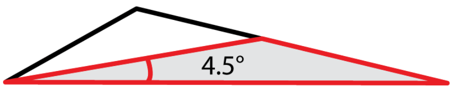


Model 10:
Waist dart.

Tilt angle: 6.3°

Dart angle: 45°

Dart leg length: 6.7 cm

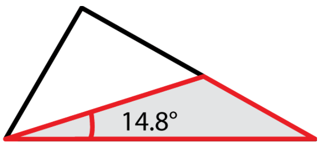


Model 11:
Shoulder tip dart.

Tilt angle: 4.5°

Dart angle: 42°

Dart leg length: 9.4 cm



Model 12:
Centre front dart.

Tilt angle: 14.8°

Dart angle: 52°

Dart leg length: 3.3 cm

Figure 5: Using the formula for the cone, the tilt angle of the cone can be calculated. This shows that the different cones have different tilt angles. It is also possible to physically measure paper models of these cones, but this can be difficult and inaccurate.

Conclusion

The experiment shows that there is a correlation between moving the dart apex and the tilt of the cone. The more the apex is moved, the greater the tilt angle of the cone.

Experiment 26: The Effect of Moving Apexes of Darts

Rationale

This experiment observes the effect of a dart apex being moved in a pattern. Moving the location of dart apexes tends to change the dart's geometric properties. It tests these properties by moving dart apexes in different directions.

Hypothesis

The research anticipates that moving the apex of the darts will change the dart angles of the cone and the cone's tilt.

Experimental Design

In a series of iterations, the dart apex is moved towards, away from, and to left and right of the garment. It observes the way the cone angle of the dart is tilted, thereby changing the dart angle of the pattern.

Procedure

The experiment is in four parts.

Part 1: Moving the apex beyond bust point

The first part tests what happens when a dart apex is moved beyond the original dart apex. Compare a dart at bust point and a dart that is moved away from the dart apex.

A dart moved away from bust dart

Model 1: Start with a block dart pattern, with a dart centred at bust point. The bust point dart should be drawn in red. Draw a new pattern with a dart 0.8 cm away from the bust dart in black. Draw a circle with a compass centred on the bust dart that has the radius of the length of the dart. Draw another line centred on the dart moved away from bust point, and let the radius of the circle be the distance from the apex to the edge of the pattern. Shade the crescent shape between these patterns in grey to show how the cone of the pattern tilts.

Model 2: Recreate model 1 and cut around the outer circle of the pattern.

Model 3: Recreate model 1 and construct the pattern in 3D.

Model 4: Recreate model 2 and construct the pattern in 3D.

A dart moved beyond bust dart

Model 5: Start with a block dart pattern, with a dart centred at bust point. The bust point dart should be drawn in black. Draw a new pattern with a dart 0.8 cm beyond the bust dart in red. Draw a circle with a compass centred on the bust dart that has the radius of the length of the dart. Draw another line centred on the dart moved beyond bust point and let the radius of the circle be the distance from the apex to the edge of the pattern. Shade the crescent shape between these patterns in grey to show how the cone of the pattern tilts.

Model 6: Recreate model 4 in 3D.

Observe the direction in which the cone tilts.

Comparing darts with different apex locations

Model 7: Recreate model 6. This is a pattern with a dart moved beyond the bust dart.

Model 8: Create a block pattern with a dart centred at bust point. Draw a circle centred on bust point with a radius of the length of the dart leg. Draw an additional pattern with a radius of 0.8 cm less than the dart leg. Shade the area between the circles to show the tilt of the cone.

Model 9: Recreate model 3. This is a pattern with a dart moved away from bust dart.

Compare the direction the cone tilts.

<u>Part 2</u>: Measuring the dart angle of a dart moved beyond bust point

The second part of the experiment tests how the dart angle of the pattern changes when apex is moved beyond bust point.

Model 10: Start with a block dart pattern with a dart centred at bust point. Draw the bust point dart in black. Draw a circle with a compass centred on the bust dart that has the radius of the length of the dart. Extend the bust point 8mm beyond bust point and draw a new dart in red. Draw another circle with a radius of the distance to the edge of the pattern. Shade the crescent shape between these patterns in grey to show how the cone of the pattern tilts.

Model 11: Cut around the large circle in the pattern to focus on the different in dart angle. Highlight in red the dart angle of the dart that is beyond bust point. Measure the dart angle.

Model 12: Highlight in red the dart at bust point and measure the dart angle.

Observe the difference in dart angle between model 11 and 12.

Part 3: An alternative method of demonstrating cone tilt

The third part of the experiment offers an alternative way of observing how moving the dart angle of the pattern tilts its cone shape.

Model 13: Create a block pattern with a dart centred on bust point. This dart is outlined in black. Draw a circle around the outside of this pattern in black. Draw a dart that is moved 0.8 cm beyond the bust point in red. Draw a circle in red that is centred on the dart beyond bust point and has a dart radius that is 0.8 cm more than the previous circle.

Model 14: Create a block pattern with a dart centred on bust point. This dart is outlined in black. Draw a circle around the outside of this pattern in black. Draw a circle in red that is centred on bust point and has a dart radius that is 0.8 cm more than the previous circle.

Model 15: Create a block pattern with a dart centred on bust point. This dart is outlined in black. Draw a circle around the outside of this pattern in black. Draw a dart that is moved 0.8 cm away from the bust point the dart in red. Draw a circle in red that is centred on the dart moved away from bust point and has a dart radius that is 0.8 cm more than the previous circle.

Model 16: Recreate model 13 in 3D.

Model 17: Recreate model 14 in 3D.

Model 18: Recreate model 15 in 3D.

Observe the direction in which the cone tilts in the different models.

Part 4: Moving the dart apex to the left and right of bust point

The fourth part of the experiment will explore how moving the dart apex to the left and right of bust point affects the dart angle and three-dimensional form of the pattern.

Moving the apex left of the bust point

Model 19: Start with a block dart pattern with a dart centred at bust point. The bust point dart should be drawn in black. Draw a new pattern with a dart moved to the left of bust point by 0.8 cm and draw the dart in red. Draw a circle with a compass centred on the bust dart that has the radius of the length of the dart. Draw another line centred on the dart moved to the left of bust point and let the radius be 0.8 cm less than the previous circle. Shade the crescent shape between these patterns in grey to show how the cone of the pattern tilts.

Model 20: Recreate model 19 in 3D.

Observe the direction in which the cone tilts.

The asymmetrical properties of darts moved to the left of the apex

Model 21: Recreate model 19.

Model 22: Recreate model 1.

Model 23: Recreate model 19. Draw a dotted red line from the apex which divides the dart in half. This should show how the dart with the apex moved left of the pattern is asymmetrical.

Model 24: Recreate model 1. Draw a dotted red line from the apex which divides the dart in half. This should show how the dart with the apex moved away from the pattern is symmetrical.

Observe the symmetry of the dart moved to the left of bust point compared to the dart moved away from the apex.

Moving the dart apex to the left affects dart angle

Model 25: Recreate mode 19 and measure the angle of the dart at bust point.

Model 26: Recreate model 19 and measure the angle of the dart moved to the left of bust point.

Model 27: Recreate model 19 and moved the dart even further to the left of bust point, then measure the dart angle. Draw a circle in purple centred on the dart apex with a radius that touches the edge of the large circle centred at bust point.

Model 28: Recreate model 19 and moved the dart even further to the left of bust point and then measure the dart angle. Draw a circle in blue centred on the dart apex with a radius that touches the edge of the large circle centred at bust point.

Compare how the dart changes its angle as it moves away from bust point.

Model 29: Recreate model 8.

Model 30: Recreate model 20.

Observe the direction in which the cone tilts.

Moving the apex right of the bust point

Model 31: Start with a block dart pattern with a dart centred at bust point. The bust point dart should be drawn in black. Draw a new pattern with a dart moved to the right of bust point by 0.8 cm and draw the dart in red. Draw a circle with a compass centred on the bust dart that has the radius of the length of the dart. Draw another line centred on the dart moved to the right of bust point, and let the radius be 0.8 cm less than the previous circle. Shade the crescent shape between these patterns in grey to show how the cone of the pattern tilts.

Model 32: Recreate model 31 in 3D.

Moving the dart apex to the right affects dart angle

Model 33: Recreate model 31 and measure the angle of the dart at bust point.

Model 34: Recreate model 31 and measure the angle of the dart moved to the right of bust point.

Model 35: Recreate model 31 and moved the dart even further to the right of bust point, then measure the dart angle. Draw a circle in purple centred on the dart apex with a radius that touches the edge of the large circle centred at bust point.

Model 36: Recreate model 31 and moved the dart even further to the right of bust point, then measure the dart angle. Draw a circle in blue centred on the dart apex with a radius that touches the edge of the large circle centred at bust point.

Compare how the dart changes its angle as it moves away from bust point.

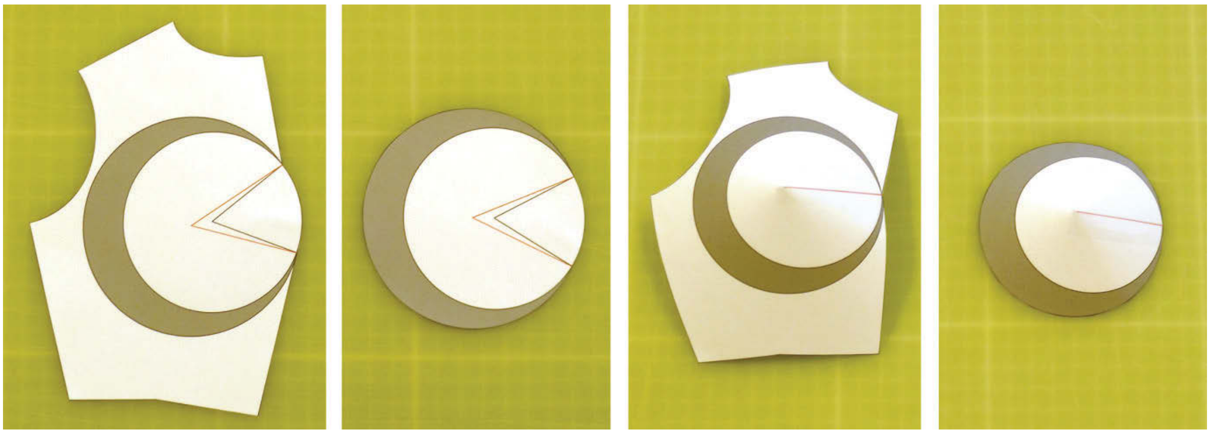
Model 37: Recreate model 8.

Model 38: Recreate model 31.

Observe the direction in which the cone tilts.

Results

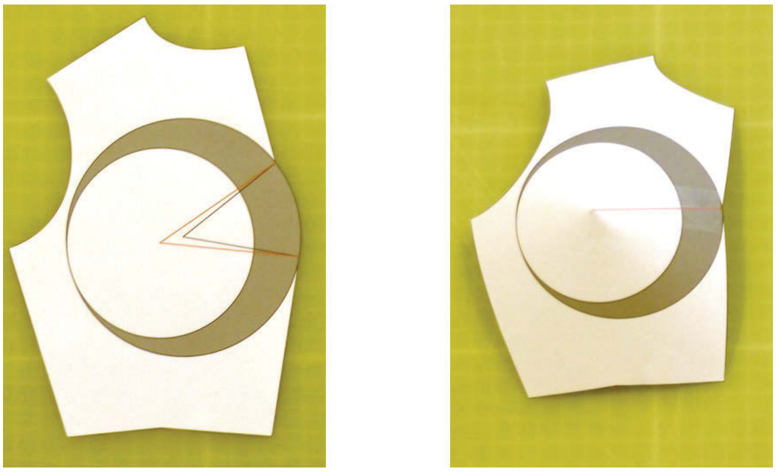
Part 1: Moving the apex beyond bust point



Model 1 Model 2 Model 3 Model 4

Flat Pattern 3D Pattern

Figure 1: A dart is manipulated so that the apex is moved beyond the bust point dart. Two circles are drawn around the apex points. The circles are then cut out of the pattern to show how moving the apex affects a cone.



Flat Pattern 3D Pattern

Model 5 Model 6

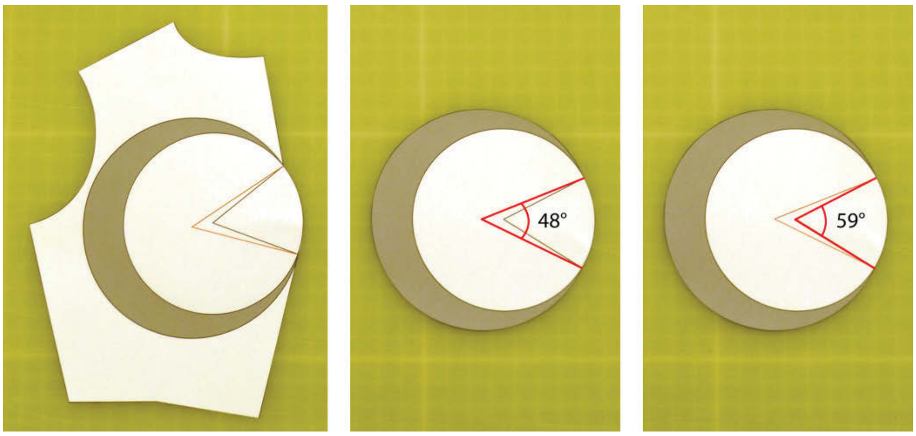
Figure 2: The white circle is a right cone drawn around the apex of the dart. This right cone is tilted by the shaded crescent shape.

Model 7:	Model 8:	Model 9:
Dart moved beyond bust point apex.	Dart at bust point.	Dart moved away from bust point apex.
This dart tilts to the left.	This dart does not tilt in any direction	This dart tilts to the right.

Figure 3: The dart moved beyond bust point (model 7) tilts the cone in a different direction from both the bust dart (model 8) and the dart moved away from bust point (model 9).

It is observed that moving the location of the apex point tilts the position of the cone in a different direction from the original shape. In model 7, moving the dart beyond bust point tilted the cone to the left. In model 9 the dart is moved away from bust point and the pattern is tilted to the right.

<u>Part 2</u>: Measuring the dart angle of a dart moved beyond bust point



Model 10:	Model 11:	Model 12:
The flat pattern.	The dart angle at bust point is 48°.	The dart angle at bust point is 59°.
	This is less than the new dart.	This is greater than the dart at bust point.

Figure 4: The dart moved beyond bust point has a lesser dart angle than the dart at bust point.

It is observed that the dart angle of the apex moved beyond bust point (model 11) is 11° less than the apex at bust point (model 59°).

Part 3: An alternative method of demonstrating cone tilt

Flat | Flat | Flat

Model 13:
Dart moved beyond bust point apex. The entire pattern tilts downwards. The dart angle is smaller than at bust point.

Model 14:
Dart at bust point. This entire pattern does not tilt in any direction. The dart angle is the same as bust point.

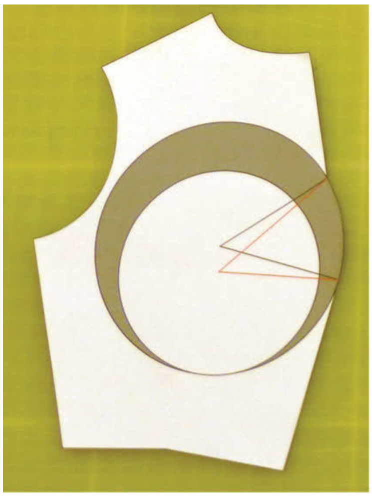
Model 15:
Dart moved away from bust point apex. The entire pattern tilts upwards. The dart angle is larger than at bust point.

3D Model 16 | 3D Model 17 | 3D Model 18

Figure 5: By drawing circles centred on the new dart apex and on bust point, it reveals the way moving the dart tilts the direction of the pattern.

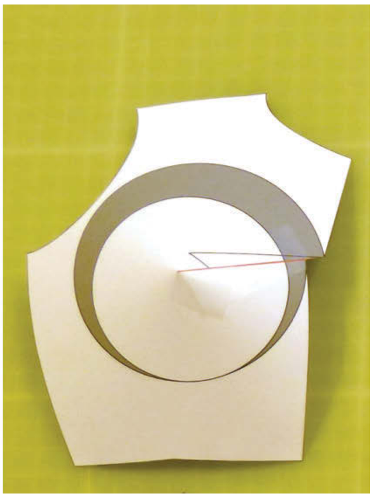
It is observed that moving the position of the apex tilts the cone in the direction the dart is moved.

<u>Part 4</u>: Moving the dart apex to the left and right of bust point



Flat Pattern

Model 19



3D Pattern

Model 20

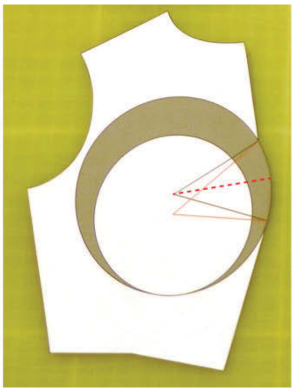
Figure 6: The new dart is drawn to the left side of bust dart. The bust point dart has the black line while the new dart left of bust point has a red line. A grey circle is drawn centred around bust point, while a white circle makes a right cone and is centred on the new dart apex.

Model 21:

Dart with apex moved left of bust point.

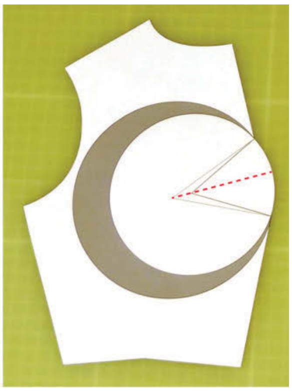
Model 22:

Dart with apex moved away from bust point.



Model 23:

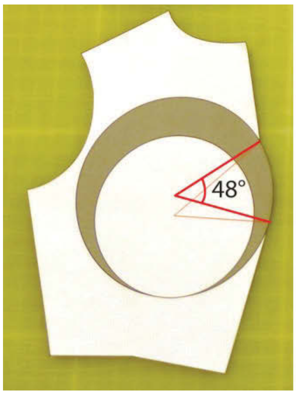
This dart is asymmetrical. The pattern is asymmetrical on the red line of symmetry.



Model 24:

This dart is symmetrical. The pattern is mirrored on the red line of symmetry.

Figure 7: The dart with the apex left of bust point (model 21) is different from the dart moved away from bust point (model 22). The apex to the left of bust point is asymmetrical (model 23), while the apex away from bust point is symmetrical (model 24).

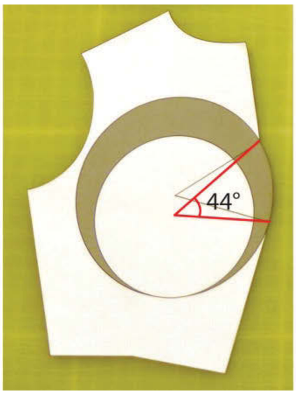


Model 25:

Dart apex at bust point.

This angle is greater than

the dart left of the dart.

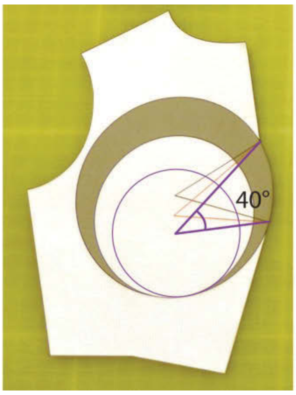


Model 26:

Dart with apex moved left of

bust point. This angle is less

than bust point.



Model 27:

A dart is drawn even

further left of bust point.

This angle is even smaller.

Model 28:

A dart is drawn even

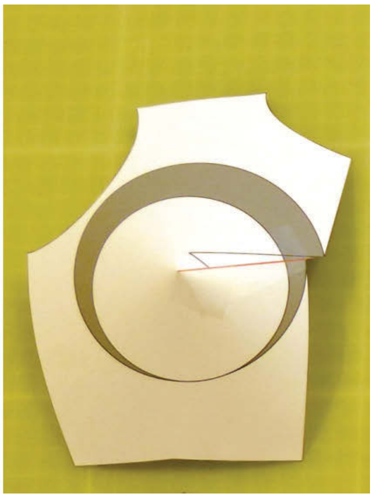
further left of bust point.

This angle is even smaller.

Figure 8: The dart left of bust point has a smaller angle than bust point. By continuing to draw darts further to the left, the dart angle continues to decrease.

Model 29:

Dart centred at bust point.

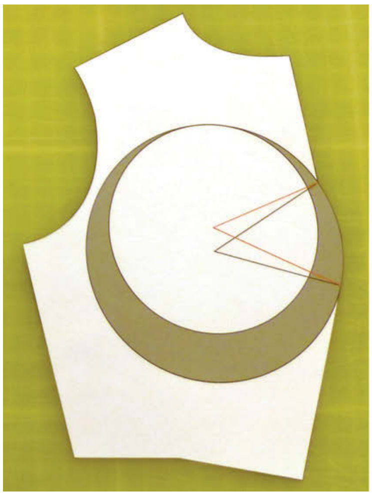


Model 30:

Dart left of bust point tilts the

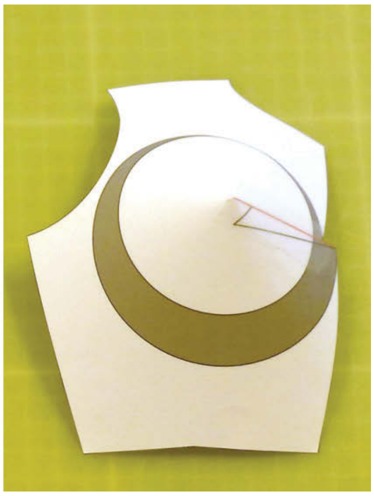
entire pattern left of bust point.

Figure 9: Placing a white cone at the dart apex shows which direction the cone is tilting. The left side cone tilts the pattern in the direction left of bust point.



Flat Pattern

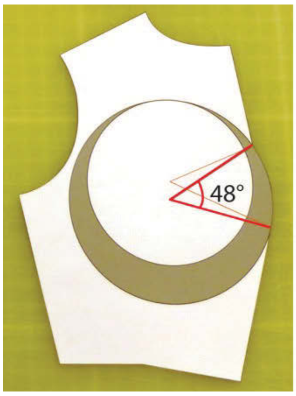
Model 31



3D Pattern

Model 32

Figure 10: The new dart is drawn to the right side of bust dart. The bust point dart has the black line while the new dart left of bust point has a red line. A grey circle is drawn centred around bust point, while a white circle makes a right cone and is centred on the new dart apex.

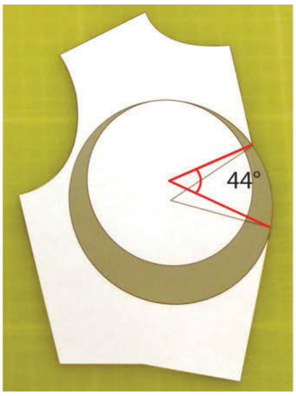


Model 33:

Dart apex at bust point.

This angle is greater than

the dart right of the dart.

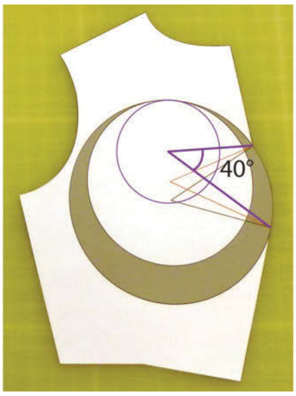


Model 34:

Dart with apex moved right of

bust point. This angle is less

than bust point.



Model 35:

A dart is drawn even

further right of bust point.

This angle is even smaller.

Model 36:

A dart is drawn even

further right of bust point.

This angle is even smaller.

Figure 11: The dart right of bust point has a smaller angle than bust point. By continuing to draw darts further to the right the dart angle continues to decrease.

Model 37:

Dart at bust point

Model 38:

3D Pattern

Figure 12: Placing a white cone at the dart apex show which direction the cone is tilting. The right side cone tilts the pattern in the direction right of bust point.

It is observed that moving the location of the apex to the left or right of the bust point decreases its dart angle. Decreasing the dart angle reduced the height of the cone. Moving the dart apex also tilts the cone in the direction that the dart apex is moved.

Conclusion

The experiment demonstrates that moving the dart apex beyond or away from the dart apex tilts the angle of the cone. Moving the dart away from the cone increases the dart angle, while moving the cone beyond the apex decreases the dart angle. Moving the dart apex to the left or right of the pattern makes the pattern asymmetrical, tilting the cone in the direction that the dart is being moved. The further the dart is being moved to the left or right of the pattern, the less the size of the dart angle.

Experiment 27: The Effect of Re-drawing Contours, Moving Apexes of Darts

Rationale

This experiment demonstrates that re-drawing contours has the effect of moving many apex points. It has been shown that by moving a single apex point, the geometric properties of a pattern can be dramatically changed. This experiment demonstrates how re-drawing contours (a common practise in patternmaking) has the effect of moving multiple apex points. This re-drawing of patterns is commonly used in techniques such as blending, truing and easing.

Hypothesis

The research anticipates that re-drawing a contour has the effect of moving multiple apex points.

Experimental Design

The experiment tests whether changing the pattern's contour lines affects the location of the apex points. It takes an example from a patternmaking textbook where a pattern with straight edges is blended into a smooth curve. It compares two different patterns and applies contour manipulation to both, to see if re-drawing the pattern moves the apex points. It then compares the apexes of the patterns.

Procedure

The experiment starts by replicating a book pattern that uses a blending technique (see figure 1). The original pattern is curved by replacing the straight lines with curved lines. The pattern is then redrawn as a pattern on a computer. This allows the patterns to be manipulated without losing geometric accuracy. Then apply contour manipulation to both, to understand their structure in the form of darts, gussets and apex points. Following this, compare them to see the effect of blending the patterns.

Model 1: Use the technique used by Assembil Books 2013, pp. 309 - 310 and trace the original pattern in figure 1.

Model 2: Trace the blended pattern in figure 1. In this pattern replicate the curve as a series of tangents so that contour manipulation can be used on the pattern.

Model 3: Replicate model 1 and identify the apex points of the pattern. Draw straight lines from the apex points to the edge of the pattern.

Model 4: Replicate model 2 and identify the apex points of the pattern. Draw straight lines from the apex points to the edge of the pattern.

Model 5: Use contour manipulation to pivot the curves until they form a straight line. This should create several darts. Colour each of these patterns with a different colour.

Model 6: Use contour manipulation to pivot the curves until they form a straight line. This should create several darts. Colour each of these patterns with a different colour.

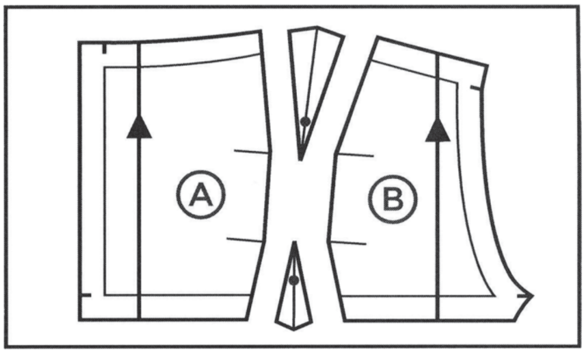
Model 7: Replicate model 5. Move the two patterns together so that they join down the seam line, and observe the configuration of apex points and darts.

Model 8: Replicate model 6. Move the two patterns together so that they join down the seam line, and observe the configuration of apex points and darts.

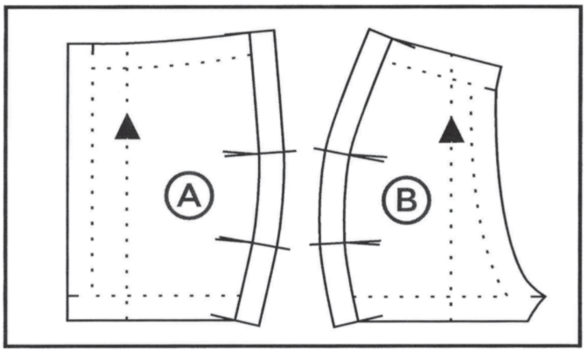
Observe the structure of these patterns.

<u>Results</u>

Set 1:

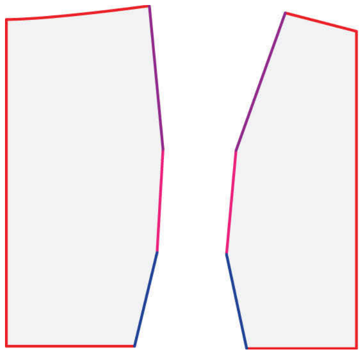


The original pattern: (Assembil 2013, p. 309).



The blended pattern: (Assembil 2013, p. 310).

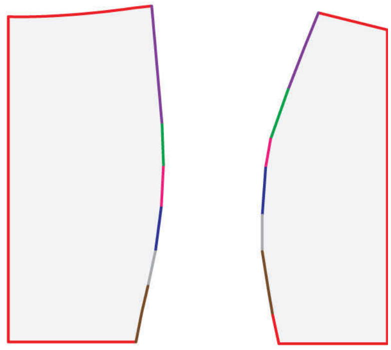
Figure 1: In this blending technique the patternmaker takes a pattern with sharp edges and blends it into a smooth edge (Assembil 2013, pp. 309 – 312). This practise may appear to effect a subtle change, but reshaping the pattern moves multiple apex points and dramatically changes the three-dimensional shape of the garment.



Model 1:

The original pattern.

Coloured lines show the tangents on the contour.

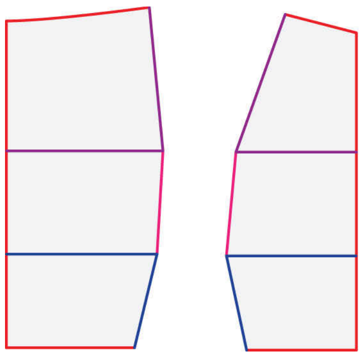


Model 2:

The blended pattern.

Coloured lines show the tangents on the contour.

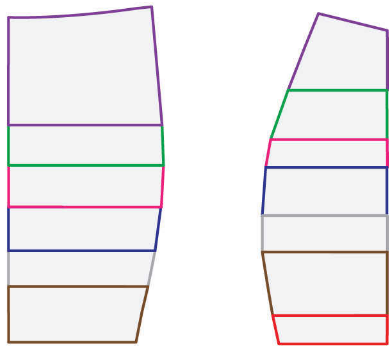
Figure 2: A pattern compared to a blended pattern. Analysing the pattern using contour manipulation, the curved edge is deconstructed into a series of tangents. The blended pattern has far more tangents than the original pattern.



Model 3:

The original pattern.

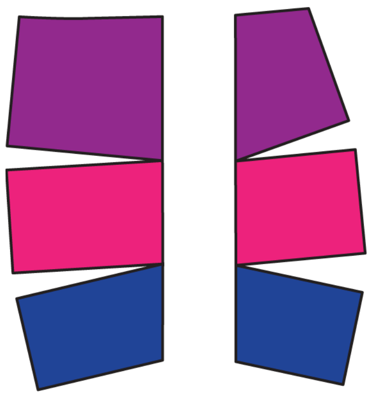
Lines are drawn from the apexes to the edge of the garment.



Model 4:

The blended pattern.

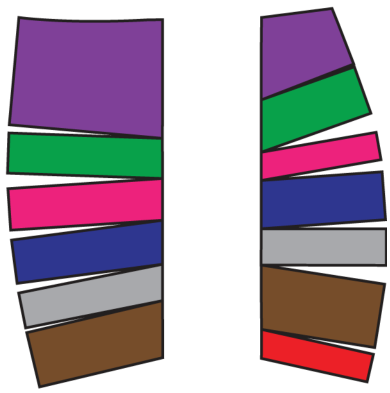
Lines are drawn from the apexes to the edge of the garment.



Model 5:

The original pattern.

The patterns are pivoted so the contour forms a straight line.

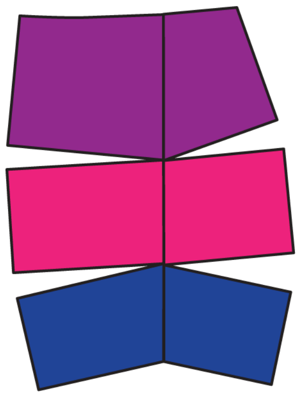


Model 6:

The blended pattern.

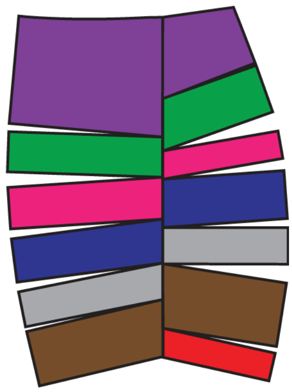
The patterns are pivoted so the contour forms a straight line.

Figure 3: An original pattern and blended pattern are analysed with contour manipulation. The curved line is straightened, revealing a series of apex points. This iteration reveals that changing the shape of the edge dramatically changes the pattern shape.



Model 7:

The original pattern.



Model 8:

The blended pattern.

Figure 4: Re-shaping the edges of patterns has the effect of adding or moving multiple apexes to a pattern. The original pattern and blended pattern become two completely different geometric identities.

The two patterns have different numbers of apex points and are in fact different pattern configurations. The technique of blending the pattern pieces moves multiple apex points and changes the sizes of many darts. The original and new pattern are two completely different shapes and are not geometric equivalent.

Conclusion

The experiment shows that re-drawing the edge of a pattern has the effect of moving multiple apex points. Techniques that require patterns to be re-drawn in different configurations actually change the shape and fit of the garment. Some changes may be great, others minor, but patternmakers may use contour manipulation to see to what extent they are changing a pattern, and what effect it will have on the final pattern.

8. Re-Evaluating Traditional Bust Point Manipulation

Experiment 28: **Re-evaluating bust point dart manipulation**

Experiment 29: **An alternative approach to fitting a bust point dart**

Experiment 30: **An alternative approach to bust point dart manipulation**

Experiment 31: **Testing cone tips of different shapes**

Experiment 32: **An alternative method for bust point manipulation with multiple darts**

Aim

This set of five experiments re-evaluates the technique of traditional bust point manipulation from a geometric perspective. It explores alternative approaches to this technique that allows a designer to move the location of the dart while maintaining the fit of the original garment. The key motivation for moving the dart apex is to avoid creating an undesirable shape at bust point. An alternative approach is to simply cut the tip off the cone with the undesirable pointed shape and replace it with a cone tip that curves on the bust. This approach ensures the same fit as the original pattern and gives the patternmaker creative freedom to choose the cone tip they want. The experiments investigate how different cone tips create different effects. It also examines how to move multiple darts around bust point while maintaining the same garment fit.

Method

The first experiment investigates if it is possible to create the same effect as traditional bust point manipulation without moving the dart apex point. The second experiment re-evaluates traditional bust point manipulation from a geometric perspective, offering an alternative approach. It tests a method wherein the tip of cone at bust point is cut off and replaced by a different cone tip with a curved shape on the bust. The third experiment demonstrates a method that moves the dart around the bust while keeping the same fit as the original garment, while the fourth explores how different-shaped cone tips can create curved shapes at bust point. The fifth experiment tests a method that allows multiple darts to be moved around bust point while maintaining the original garment fit.

Analysis

This group of experiments re-evaluates the underlying principles of bust point manipulation and offers an alternative approach. The first test shows that it is not always possible to get the same effect as bust point manipulation without moving the dart apex. Some darts can create a similar appearance, but others that cross the bust point deliver a very different aesthetic. There is a need for a technique that can move the location of dart apexes while delivering a similar fit to the original garment. The subsequent experiments question the need to move the location of the bust point dart. They reason that in a block dart where the majority of the garment fits well, it is only the tip of cone that has an undesirable shape. In the alternative approach, the tip of cone is cut off and replaced with a cone that creates a curved surface.

This alternative to bust point manipulation maintains the same fit as the original garment while moving the location of the dart apex. By applying principles of conics it is possible to move the style lines on the base of the dart using dart manipulation. The cone tip is replaced by a cone with its tip moved away from bust point, and it can be rotated to move the location of the apex and align with the style line on the base of the cone. This in fact is a way of moving the location of the dart and its apex while maintaining the same surface area, volume and fit of the original garment. The cone tip can be interchanged with cone tips of different styles, giving the patternmaker many creative options. It is even possible to use this technique to divide a dart into multiple darts or to move the location of multiple darts.

Experiment 28: Re-Evaluating Bust Point Dart Manipulation

Rationale

This experiment tests whether is possible to re-create the effect of the bust point manipulation technique without moving the apex of the dart. The goal of bust point dart manipulation is to move the dart around the garment while maintaining the same fit. Moving the apex of the dart creates the desired design but also changes the three-dimensional form, dart angle and surface area of the garment. Creating a dart with the same apex location is one way to create a garment with the same fit. The experiment therefore tests the necessary of moving the apex point of a garment in dart manipulation.

Hypothesis

The research anticipates that if the dart maintains the same apex location, it should have the same fit as the original garment. However, it is not certain that this will create the same effect as traditional bust point manipulation.

Experimental Design

The first part of the experiment creates the effect of a traditional bust point manipulation technique. It starts with a basic garment block pattern with a dart that is off centre from bust point. In this iteration the location of the apex is not moved, so that it keeps the fit of the original garment. Multiple dart locations are drawn from the apex point to the edge of the garment. Hereby, it investigates if any of the darts cross bust point. If darts cross bust point, they may not create the same effect as traditional bust point manipulation. The second part of the experiment compares darts that cross the bust point at different locations, testing whether it is possible for them to re-create the effect of traditional bust point manipulation.

Procedure

Set 1:

Model 1: Create a front block garment pattern with a dart moved away from bust point. The top apex is located at bust point. A circle drawn around bust point shows the distance the dart apex is moved away. A new dart is drawn with an apex off-centred from bust point. Leave this as a flat pattern.

Model 2: Construct the pattern in 3D using tape.

Model 3: Take the same flat pattern from model 1 and draw darts from the same apex point to different locations on the garment. Draw two darts that work well in green. Draw in amber two darts that almost cross over bust point. Draw in red a line that crosses over bust point.

Model 4: Using the pattern in model 2 draw multiple lines from the same apex points. Identify many of the possible places where darts can be drawn. Colour the darts in the same manner as in model 3.

Set 2:

The experiment tests whether darts that cross over bust point will create the same effect as bust point manipulation. It compares darts that cross over, partially cross over and do not cross over bust point. These garments are observed to see if they create the same effect as the bust point manipulation technique.

Model 5: Create a block garment pattern with a dart moved away from bust point (model 1). Draw three darts from the apex point to different locations on the pattern. Draw a green line from the apex to the bottom left edge of the pattern. Draw an amber line that partially crosses bust point to the top left corner of the armhole. Draw a red line through bust point to the top of the pattern.

Model 6: Using the pattern from model 5, cut down the green line.

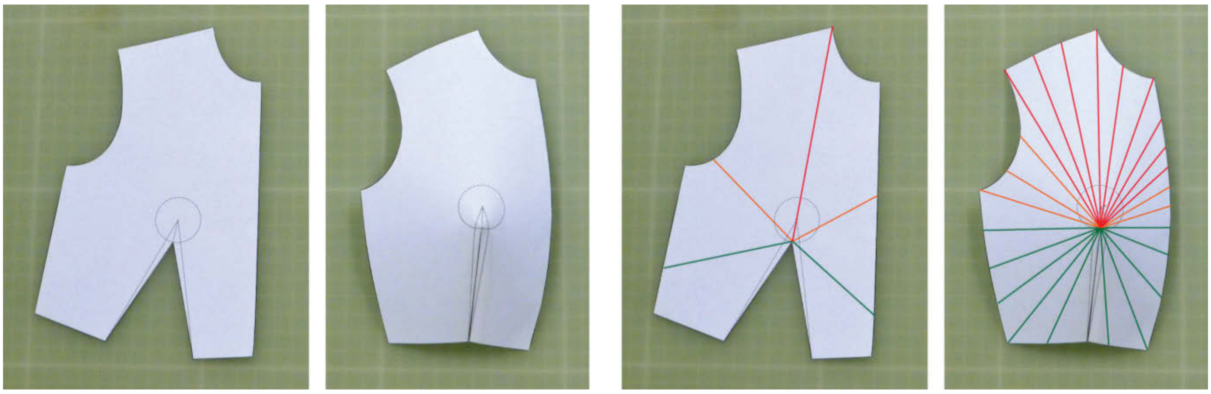
Model 7: Using the pattern from model 5, cut down the amber line.

Model 8: Using the pattern from model 5, cut down the red line.

Observe the properties of these different darts.

Results

Set 1:



Flat | 3D | Flat | 3D

Model 1:
Dart with apex away from bust point.

Model 2:
Dart with apex away from bust point.

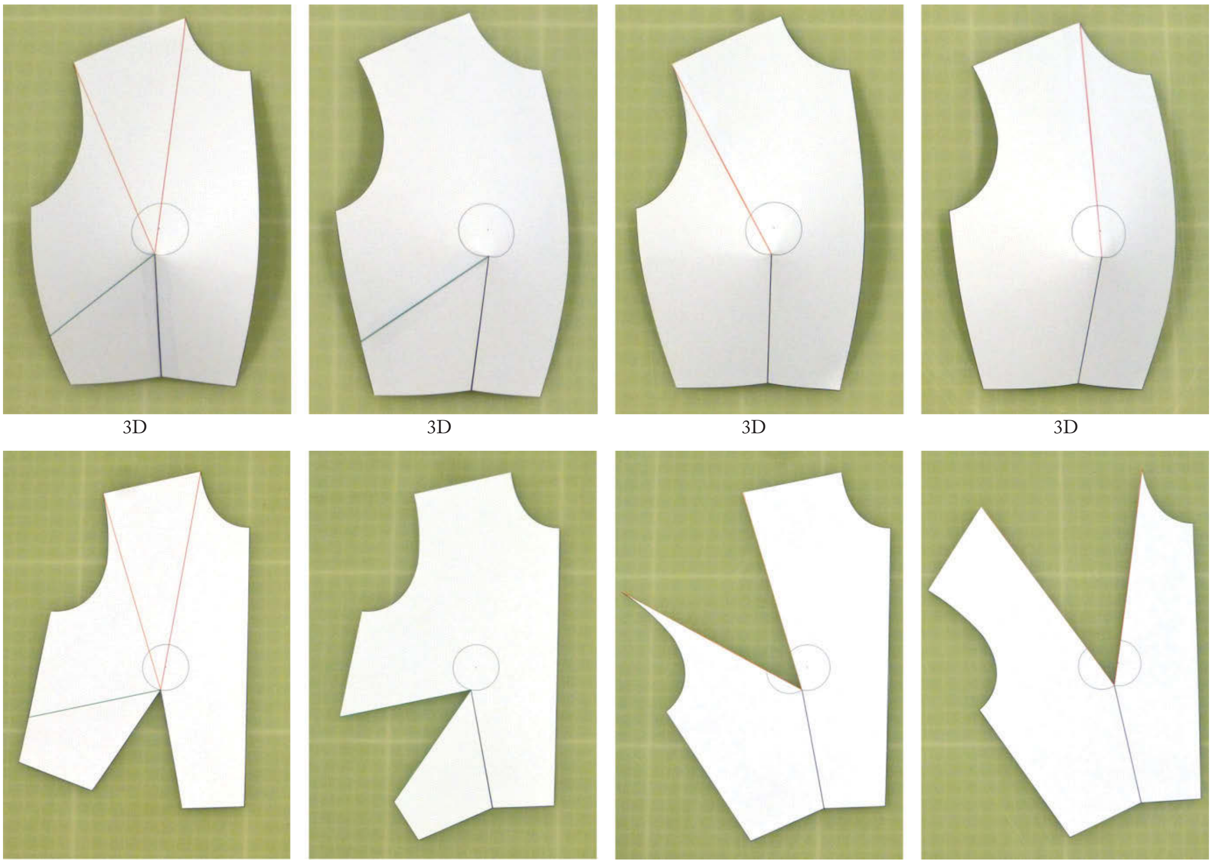
Model 3:
Some darts looks aesthetically pleasing, but others cross over the bust and do not look good.

Model 4:
Darts in red cross over the bust. Darts in amber partially cross the bust. Darts in green do not cross the bust.

Figure 1: With this technique, the darts will often cross over the top of the bust point. The darts in green work well, but the darts in amber and red cross over the bust and are not aesthetically pleasing.

It is observed in this iteration that almost half the apexes will cross or partially cross over bust point. This makes it difficult to re-create the effect of a traditional bust point manipulation where the location of the dart is moved. It is possible to re-create the effect of traditional bust point manipulation on the darts that do not cross over bust point.

Set 2:



Model 5:
Dart with apex moved away from bust dart. New dart locations drawn on pattern.

Model 6:
Aesthetically pleasing dart.

Model 7:
The dart crosses the bust and is not aesthetically pleasing.

Model 8:
The dart crosses the bust point and is not aesthetically pleasing.

Figure 2: Darts that cross the bust are not aesthetically pleasing. The green dart looks good, but the amber and red darts cross the bust and are aesthetically not pleasing.

This iteration demonstrates that the darts that partially cross over or fully cross over bust point do not create the same effect as a traditional bust point manipulation technique. Models 7 and model 8, which cross over bust point, do not create the same appearance as traditional bust point manipulation.

Conclusion

This experiment shows that it is not always possible to create the same effect as traditional bust point manipulation without moving the apex point of the dart. Keeping the dart apex in the same location may ensure that the garment has the same fit, but it does not offer the same effect. The darts that cross over bust point do not create the same aesthetic as traditional bust point manipulation. This may offer an option for darts that do not cross over bust point, but is not a solution that can replace bust point manipulation in every situation.

Experiment 29: An Alternative Approach to Fitting a Bust Point Dart

Rationale

This experiment tests an alternative approach to fitting a dart around bust point. When patternmakers draft block patterns they use a dart at bust point to calibrate their measurements. However this dart creates a pointy shape at the bust, which is undesirable for many designs. Using bust point manipulation designers move the apex of the dart away from bust point for the sake of a better shape. This approach is effective, but moving the apex of the dart changes the dart angle, surface area, volume and fit of the original garment. The research tests an alternative to bust point manipulation that seeks a better fit. It aims to create a pattern that can move the apex around the garment while maintaining the original fit, that is; the same surface area and volume.

Hypothesis

The research anticipates the creation of an alternative to the bust point manipulation technique that maintains the surface area and volume of the pattern no matter the location of the bust dart.

Experimental Design

The experiment tests an alternative to bust point manipulation, evaluating the problem from a geometric perspective. It uses block patterns, drafted from measurements taken off the body and with the most accurate fit. Most of the block pattern fits well, the only undesirable part being the tip of bust point. In traditional bust point manipulation the apex is moved away from bust point, yet this often changes the dart angle and surface area of the pattern. The current experiment uses the principle of conics wherein the block pattern is treated like a cone, with the non-fitting tip being cut off. This keeps the garment's fit while changing only the tip of the cone. Following this, it compares the alternative technique with traditional bust point manipulation.

Procedure

The first part of the experiment evaluates a block pattern from the perspective of conics. The front pattern of the dart is evaluated as a cone.

Part 1: An alternate bust point manipulation technique

Set 1:

Diagram 1: Create a diagram of the block pattern fitting the body. Evaluate the fit of the front and side view. Create a diagram of the front block pattern sitting on the front of the garment.

Diagram 2: Start with the diagram of the block pattern fitting the body. Evaluate the parts of the garment that do not fit well or have an undesirable pointy shape. Shade this portion of the diagram blue.

Diagram 3: Start with the diagram of the block pattern fitting the body. Evaluate the parts of the garment that does fit well to the body. Shade this portion of the diagram blue.

Observe the portion of the garment that fits well compared to the garment that does not fit well.

Set 2:

In the alternative to bust point manipulation, the pattern lies in different positions on the body depending on the three-dimensional form of the body. These patterns will fit the garment well and only the tip of the garment will have an undesirable fit. Bust shapes of different shapes will create garments with different-shaped cone tips. The point at which the cone is cut off the pattern will be referred to as the 'bust contact point'. This set of iterations shows the different locations and shapes of the bust contact point depending on the size and shape of the bust.

Diagram 4: Create a block pattern mounted on the body with the apex at bust point. Draw a red circle to show the point at which the pattern makes contact with the bust and where the tip of the cone can be cut off.

Diagrams 5 to 8 show bust shapes of different sizes and how these change the size and shape of the bust contact point. In these diagrams the bust contact point is illustrated as a blue circle.

Diagram 5: Create a pattern for a body with a more curvaceous bust. Draw the bust contact point in blue.

Diagram 6: Create a pattern for a body with a less curvaceous bust. Draw the bust contact point in blue.

Diagram 7: Create a pattern for a body with a more conical shaped bust. Draw the bust contact point in blue.

Creating patterns that fit in different ways can also change the shape and location of the bust contact point.

Diagram 8: Create a pattern with a flatter fit and place it on the body.

Diagram 9: Create a pattern with a regular fit and place it on the body.

Diagram 10: Create a pattern with a steeper fit and place it on the body.

Set 3:

The third part of the experiment compares the approach of moving the apex away from bust point to cutting the cone tip, and how these approaches change the fit of the garment.

Diagram 7: Create a block pattern mounted on a mannequin with the dart apex at bust point.

Diagram 8: Create a diagram of a block pattern with the dart moved away from bust point.

Diagram 9: Create a block pattern with the dart moved away from bust point. This pattern should show all the different ways moving the dart has changed the properties of the pattern. Show the location of the bust point and the new dart apex. Draw circles centred on bust point and the dart apex, in order to show how moving the dart apex tilts the angle of the cone. Shade the area between the dart at bust point and the new dart in purple, to show how moving the apex changes the surface areas of the pattern.

Diagram 10: Duplicate the pattern in diagram 9 and construct it in 3D by using tape.

Diagram 11 and 12 compare the fit of the two different approaches of manipulating the pattern at bust point. In diagram 11 the tip of the pattern that does not fit the garment is cut off. In diagram 12 the location of the apex is moved to change the garment fit. These patterns are then compared to see how well they fit.

Diagrams 11: Re-create diagram 3 from the previous experiments. Evaluate the areas of the pattern that fit compared to the areas that do not. Shade in blue the areas on the pattern that fit the garment well.

Diagrams 12: Re-create diagram 8 from the previous experiments. Evaluate the areas of the pattern that fit compared to the areas that do not. Shade in blue the areas on the pattern that fit the garment well. Note the areas where the apex of the pattern has moved, the cone has tilted, the dart angle has increased and the surface area has changed.

Set 4:

The final part of the experiment shows how to replace the cone tip with a pattern that better fits the curved part of the bust.

Models 9 to 11 demonstrate the principle of conics that allows the cone tip to be cut off.
Models 12 to 13 demonstrate how this can be applied to a block pattern.
Models 14 to 16 demonstrate how the tip can be replaced by a cone that is off-centred from bust point and smoothly curved around bust point.

Model 9: Create a cone pattern. Half way down the pattern draw a circle to create the tip of the cone. Construct the cone pattern in 3D.

Model 10: Cut the tip off the cone.

Model 11: The tip of the cone becomes a smaller cone and the base of the cone becomes a frustum.

Model 12: Start with a front block pattern and construct it in 3D. Mark the bust contact point on the pattern as a circle. Create a small circle near bust point which is the distance that the pattern would normally be moved away from bust point.

Model 13: Cut the tip off the cone.

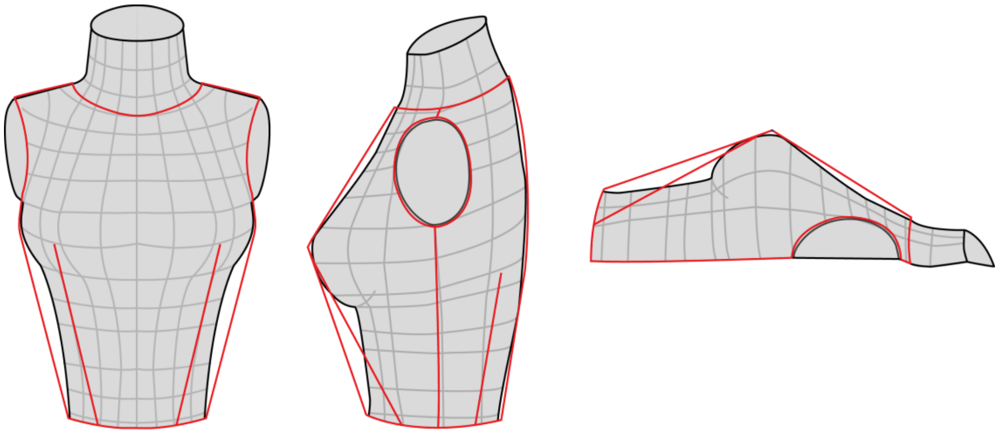
Model 14: Replace the tip of the cone with a new cone that has the dart moved so that it is away from bust point.

Model 15: Re-attach this new cone tip to the base of the pattern.

Model 16: Trace this pattern to make the new cone pattern. The pattern has the same fit as the original block dart except that the tip that did not curve smoothly around the bust has been replaced by a cone tip with a dart moved away from bust point.

Part 1: An alternate bust point manipulation technique

Set 1:



Front view of block pattern. Side view of block pattern. Side view of front of block pattern.

Diagram 1

Figure 1: The block pattern with the bust centred at bust point is accurate and the best fit, because it is created from all the linear measurements.

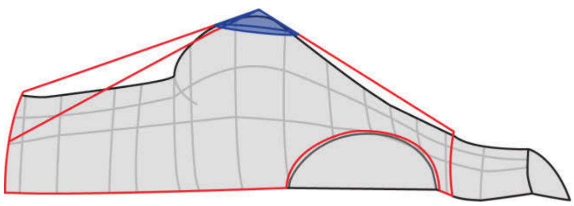


Diagram 2:
Only a very small percentage of the does not fit,
since it does not have a desirable curved shape.

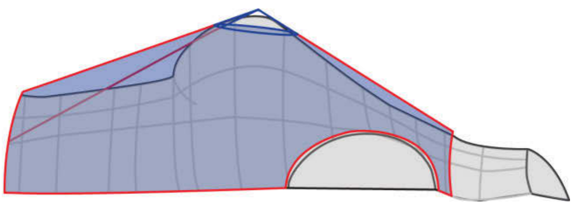
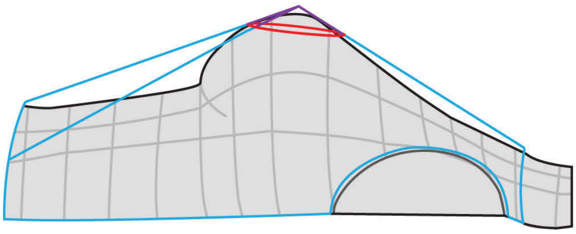


Diagram 3:
The majority of the block pattern fits very well.
This is the shape created by the measurements which are taken.

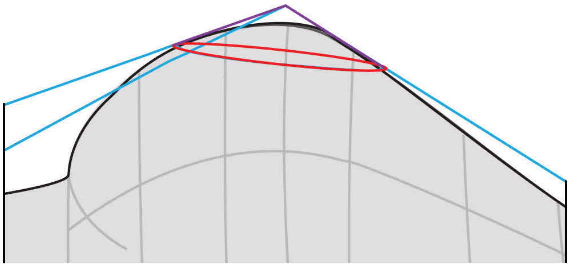
Figure 2: Compare the area of the block pattern that fits to the area that does not fit.

It is observed in this pattern that the majority of the block pattern fits well, and that only a small amount at the cone tip has an undesirable pointy shape.

Set 2:



A block pattern fitted to the body.



The pattern focussed on the bust point.

A cone shaped area at bust point does not make contact with the garment. The point of contact is the bust contact point.

Diagram 4

Figure 3: When a block pattern is fitted to the body there is a cone-shaped area (purple cone) that does not touch the body. The 'bust contact point' (red circle) is a shape that separates the part of the garment that makes contact from the part that does not.

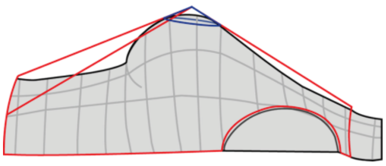


Diagram 5:

More curvaceous bust.

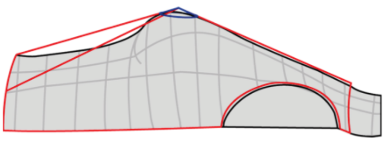


Diagram 6:

Less curvaceous bust.

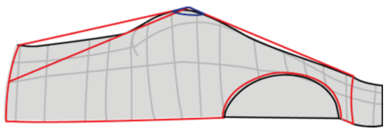


Diagram 7:

More conical shaped bust.

Figure 4: Different-shaped busts create bust contact points and cone shapes of different sizes.

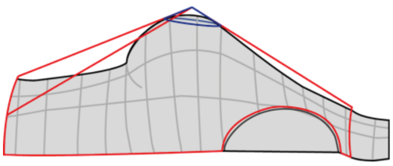


Diagram 8:

A pattern with a flatter fit.

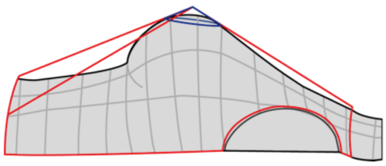


Diagram 9:

A pattern with a medium fit.

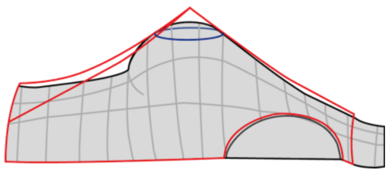


Diagram 10:

A pattern with a steeper fit.

Figure 5: Different-shaped patterns can also fit the same shape of bust in different ways, creating bust contact points and cone shapes of different sizes.

It is noted that bust shapes of different sizes can create a bust contact point of a different shape. The fit of the block pattern can also change the size and position of the bust contact point. This can put the cone tip into different shapes and sizes.

Set 3:

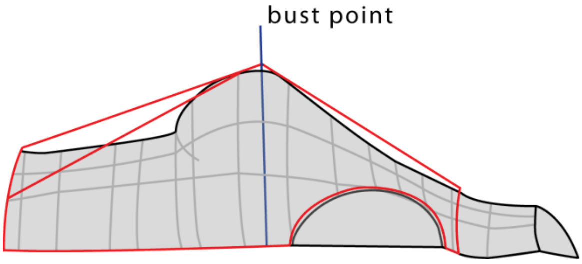


Diagram 7:

A block pattern is fitted to the dart at bust point.

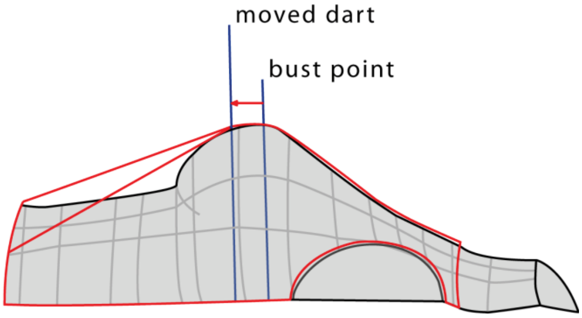


Diagram 8:

Bust point manipulation techniques move the bust point to remove the pointy shape.

Figure 6: Bust point manipulation moves the location of the bust point to avoid creating a pointy shape. However, from a geometric point of view this changes the fit of the entire pattern.

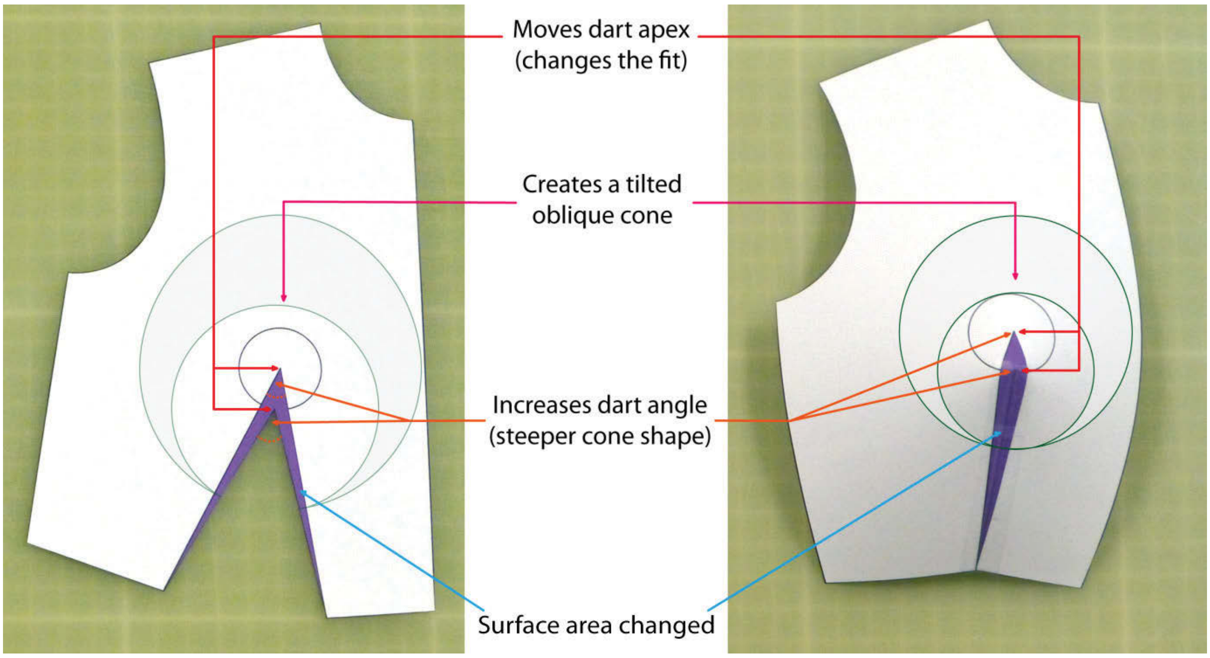


Diagram 9:

Flat pattern.

Diagram 10:

3D pattern.

Figure 7: Bust point manipulation moves the location of the dart apex, adds fullness, tilts the cone shape (creating an oblique cone) and changes the dart angle of the pattern. From a geometric point of view this changes the fit of the garment.

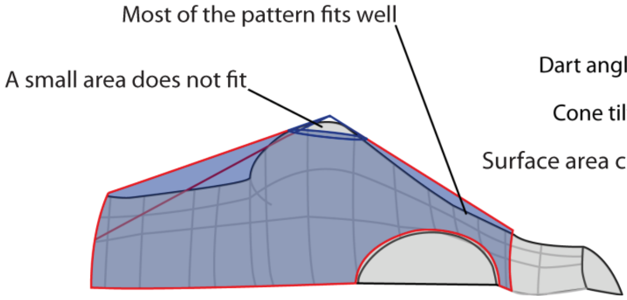


Diagram 11:

The pattern with dart at bust point.

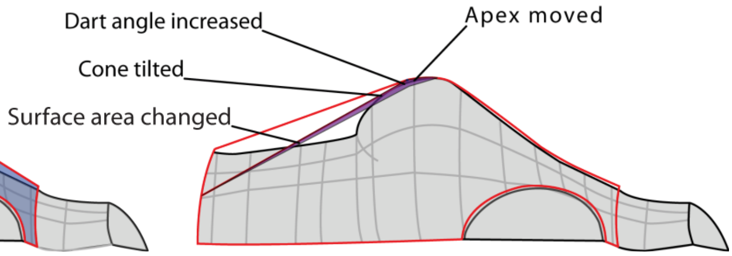


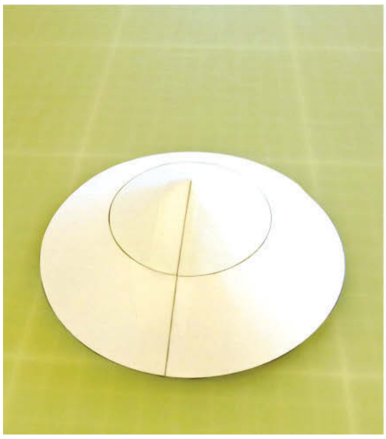
Diagram 12:

The pattern with bust point manipulation with dart apex moved.

Figure 8: The bulk of the dart at bust point fits well. Only the tip has an undesirable pointy shape. Analysing a bust point manipulation from a geometric point of view reveals that moving the apex of the dart creates many changes to the pattern shape. The new fit of a bust point manipulation is very different to the original fit of the block pattern with the dart at bust point.

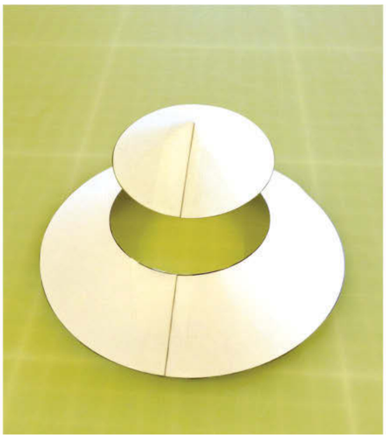
It is observed that these two techniques require different approaches. Traditional bust point manipulation moves the entire apex of the dart, removing the pointy cone shape at bust point but changing the fit of the entire garment. The alternative technique proposed by the experiment keeps the fit of the original dart block and simply removes the part of the cone tip that has an undesirable pointy shape.

Set 4:



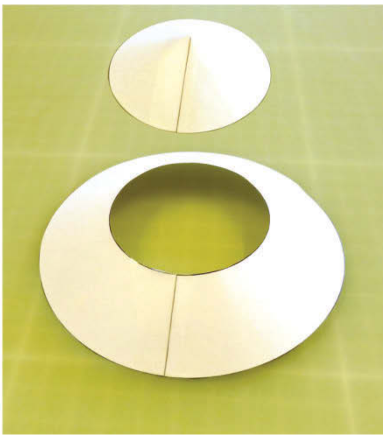
Model 9:

Cone.



Model 10:

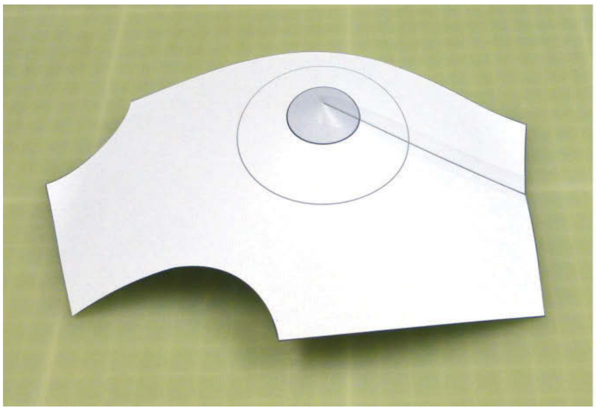
The top of the cone is cut off.



Model 11:

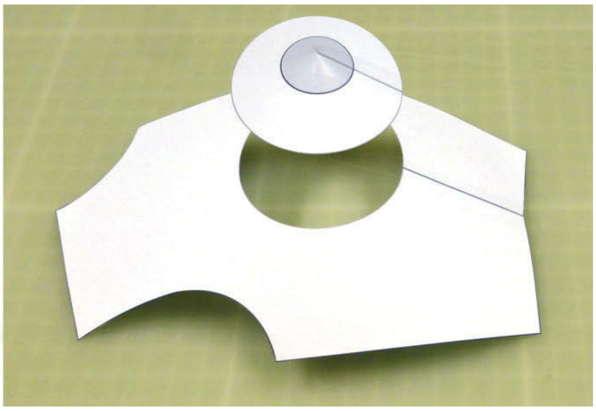
The tip of the cone is cut off and the base is a frustum shape.

Figure 9: The tip can be cut off the top of a cone creating a smaller cone and a frustum.



Model 12:

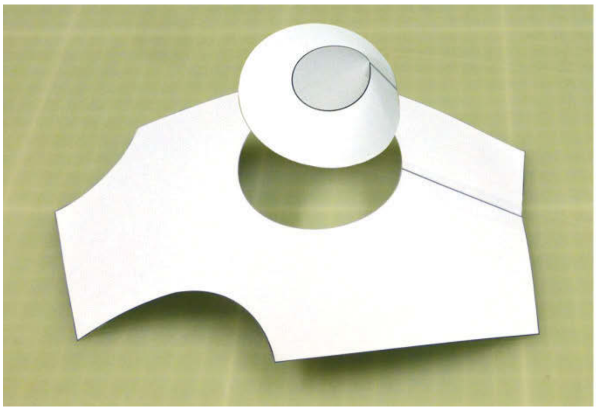
The block pattern.



Model 13:

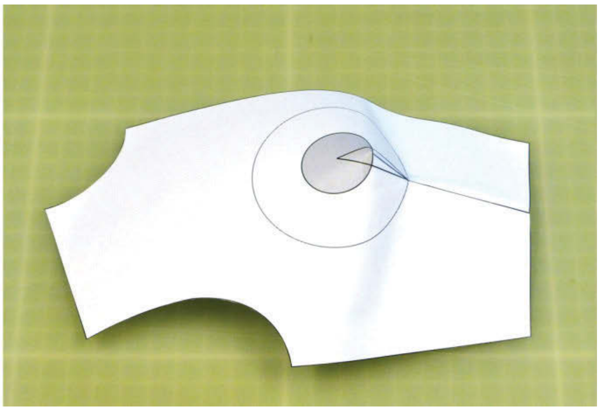
The tip of the block pattern is cut off.

Figure 10: The tip of a block pattern can be cut off, creating a cone whereby the base becomes a frustum shape. The shaded area is the distance the patternmaker may move the dart away from bust point.



Model 14:

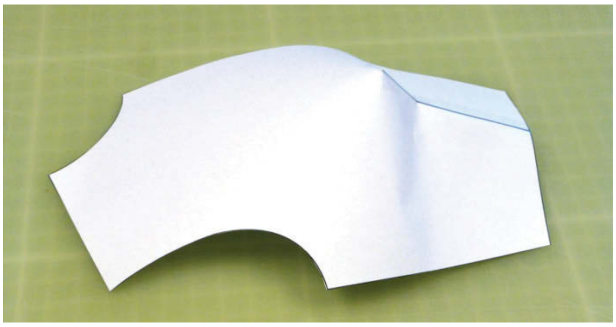
The pattern with a cone cut off the tip.



Model 15:

The pattern with the tip replaced by a shape that will curve around bust point.

Figure 11: The tip of a block pattern is replaced by a shape that can curve around bust point.



Model 16

Figure 12: The final pattern, where the majority of the pattern maintains the same fit while the pointy tip has been replaced by a pattern that can curve around bust point.

It is noted that this pattern keeps the fit of the original block pattern and simply moves the apex at the tip of the cone. In the alternative technique it is observed that the cone tip can be rotated in any direction and still be attached to the pattern. This is a way of rotating the apex around bust point while maintaining the surface area and volume. It seems to achieve the same desired effect as traditional bust point manipulation technique but with greater accuracy. One difference between bust point manipulation and the alternative, is that the new dart does not always have a straight dart leg.

Conclusion

The alternative technique appears to be an effective way to get a similar effect to traditional bust point manipulation while keeping the same fit as the block pattern. Moving the apex location in a bust point manipulation changes the dart angle and pattern surface area, while the alternative maintains the surface area of the original.

Experiment 30: An Alternative Approach to Bust Point Dart Manipulation

Rationale

This experiment tests an alternative to bust point dart manipulation that lets the patternmaker move the location of the dart apex while creating a pattern that keeps its original fit. To ensure pattern accuracy, the new pattern will have the same surface area, volume and fit as the original garment. It offers the patternmaker different creative possibilities related to shaping the tip of the bust point dart.

Hypothesis

The research anticipates an alternative to the bust point manipulation technique that can maintain the surface area and volume of the pattern no matter where the bust dart is located.

Experimental Design

The third iteration of this experiment examines the fit of the bust dart, and explores the idea of simply cutting off the tip of the bust dart and replacing it with a different-shaped pattern that blends to the contours of the body.

Procedure

This experiment offers an alternative technique to bust point manipulation, whereby the fit of the original block pattern is maintained and only the cone tip with an undesirable pointy shape is cut. The base of the pattern is manipulated using dart manipulation. This dart is centred at the original apex point. It cuts the dart tip and replaces it with a cone tip, with the dart moved away from bust point. This moves the dart apex away from bust point, smoothly curving around the bust. In fact, the cone tip can be rotated to position the dart in many locations while maintaining the volume and surface area of the garment. This ensures that darts can be put in many places without changing the fit of the original garment.

Part 1: An alternative patternmaking technique

In each of these iterations, the patterns will be duplicated as flat and 3D. This lets the patternmaker observe the technique in greater detail.

Model 1: Create a block pattern for the front of a garment. The dart is placed on the waist and the apex is centred on bust point.

Model 2: Draw the location of a new dart from bust point to the right edge of the garment.

Model 3: Draw a circle centred on bust point that will form the bust contact point. This is the tip of the cone that needs to be cut off and replaced with a cone tip of a different shape.

Model 4: Cut down the new dart, and use dart manipulation to pivot the dart to create a new dart.

Model 5: This creates a dart on the right side of the garment centred at bust point.

Model 6: Cut around the circle to remove the cone tip from the pattern.

Model 7: This pattern forms the pattern at the base of the garment.

Model 8: This pattern creates the base of the pattern and the cone tip.

Model 9: Replace this cone tip with a pattern that has the dart moved away from bust point. Draw a circle of the pattern to show the distance the dart apex is moved from bust point. Re-draw the location of the dart apex.

Model 10: Attach the new cone tip to the base of the pattern. Retrace the pattern and construct it as a new pattern.

Model 11: Create a copy of model 10 without all the dart lines to show what the pattern looks like.

Part 2:

The second section of the experiment shows the two different components of this technique. The first part is the pattern base that used a dart manipulation centred at bust point with the tip cut off the cone. The second part is the new cone tip which can be rotated to move the location of the dart apex while maintaining the surface area and volume.

Set 2:

Use the same technique in the last experiment to move the dart on the base of the pattern.

Model 12: Keep the original dart at the waist.

Model 13: Move the dart to the side of the garment.

Model 14: Move the dart to the shoulder of the garment.

Model 15: Move the dart to the neckline of the garment.

Model 16: Move the dart to the armhole of the garment.

Set 3:

Model 17: Start with the base pattern from model 12 and place the cone tip from model 9 on top of the pattern. Rotate the cone tip to show the dart apex in many different locations.

Part 3:

The third part of the experiment uses the technique in part 1 to move a dart to a different location, this time to the neckline.

Set 4:

In each model the patterns are duplicated as flat and 3D, letting the patternmaker observe the technique in greater detail.

Model 18: Create a block pattern for the front of a garment. Draw the bust contact point as a circle on the pattern. Draw the location of the new dart on the neckline.

Model 19: Cut down the dart line and pivot the pattern to create a new dart.

Model 20: Cut the tip of the dart. Replace the tip with a new cone tip with the dart apex moved away from bust point.

Model 21: Replace the cone tip with the new cone tip and attach it to the pattern using tape.

Model 22: Trace the pattern and construct a new pattern.

Set 5:

This part of the experiment compares the different pattern pieces created by the alternative bust point manipulation technique. The pattern will be compared with all the construction lines, and as the final pattern.

Model 23: Take the base pattern from model 12 and attach the same cone tip used in model 9. Shade the circle on the cone tip grey to differentiate it from the other patterns. Trace the pattern and create a second model without the construction lines.

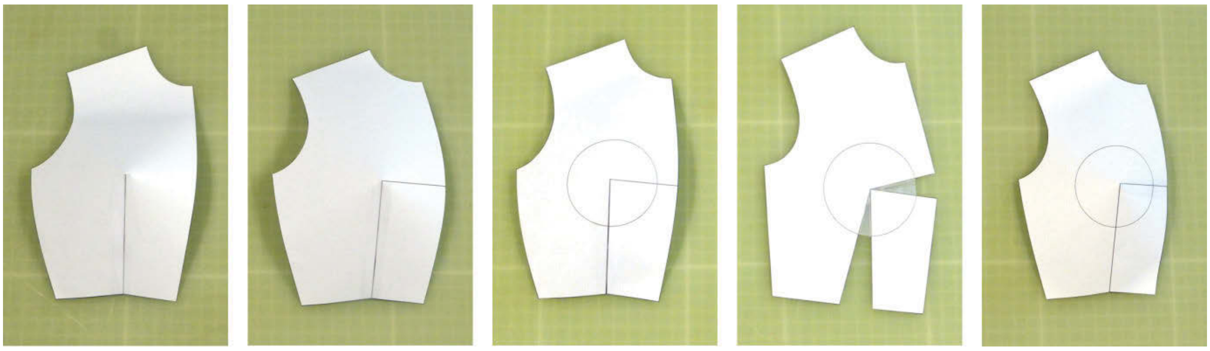
Model 24: Compare model 21 and model 22.

Model 25: Compare model 21 and model 22.

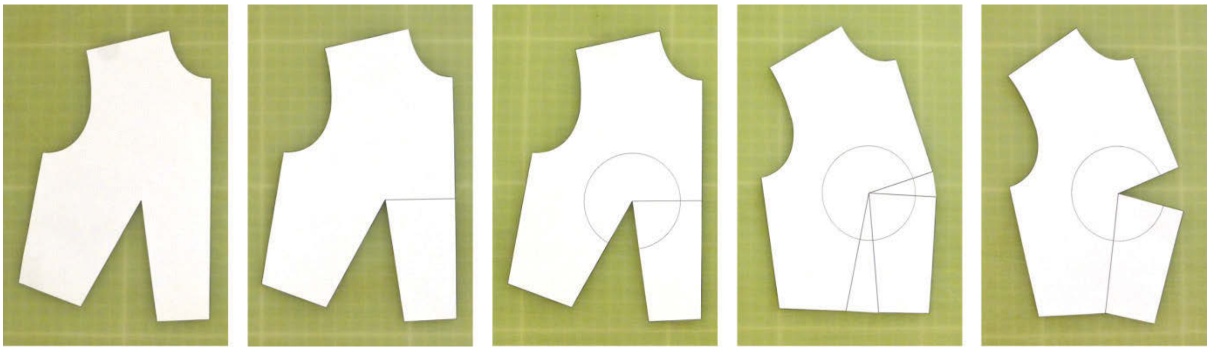
Results

Part 1: An alternative patternmaking technique

Set 1:



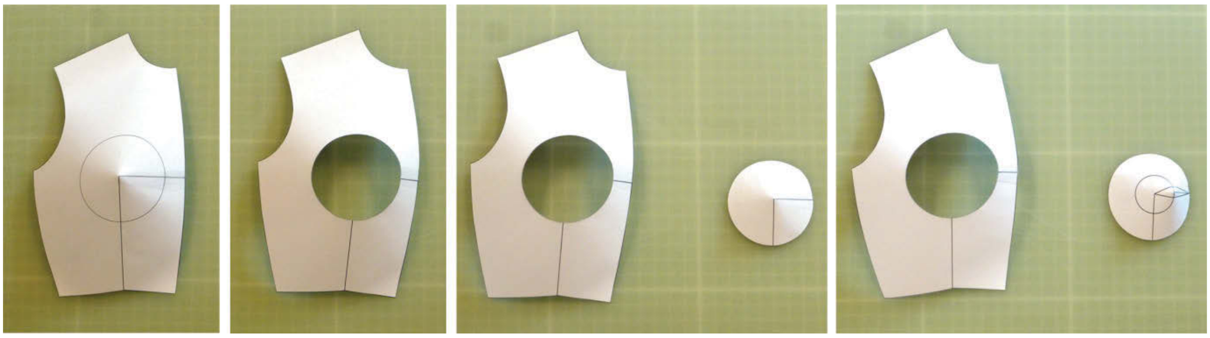
3D	3D	3D	3D	3D



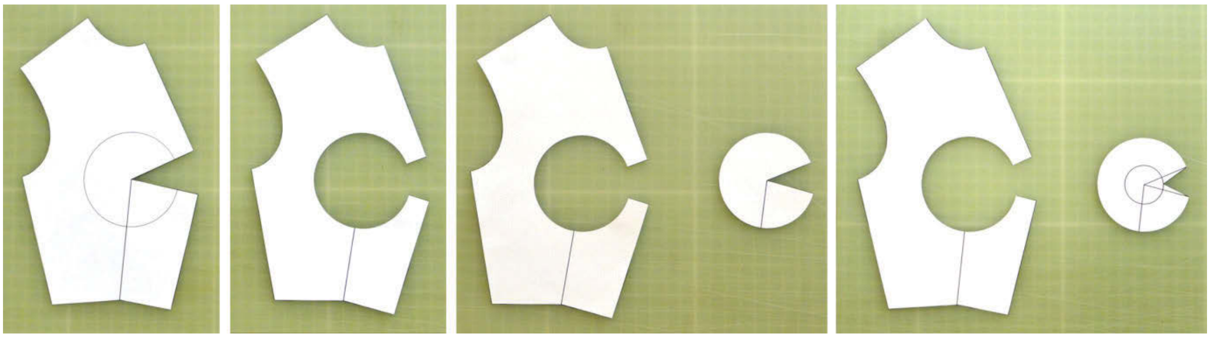
Flat.	Flat.	Flat.	Flat.	Flat.

Model 1:	Model 2:	Model 3:	Model 4:	Model 5:
A basic block pattern with apex at bust point.	The location of the new dart is drawn on the pattern.	A circle is drawn around bust point.	The pattern is cut down the style line and the dart is pivoted.	The new dart is formed on the centre front of the garment.

Figure 1: A new dart line is drawn on the basic block pattern and the dart is moved at bust point to the new location.



3D | 3D | 3D | 3D



Flat | Flat | Flat | Flat

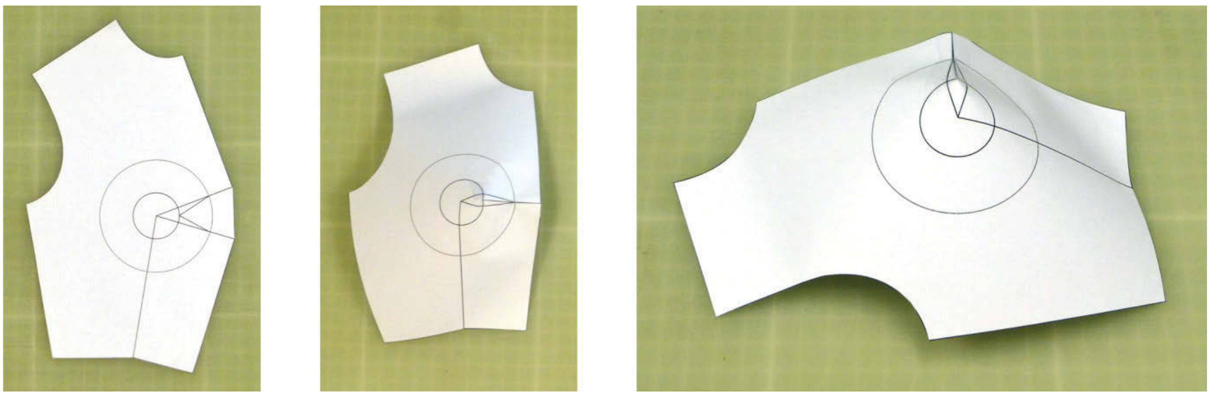
Model 6:
The tip of the cone is cut off by cutting on the circle.

Model 7:
The tip of the cone is cut off.

Model 8:
The pattern is deconstructed into the base pattern and a cone.

Model 9:
The cone is replaced with a pattern that does not create a pointed shape at bust point.

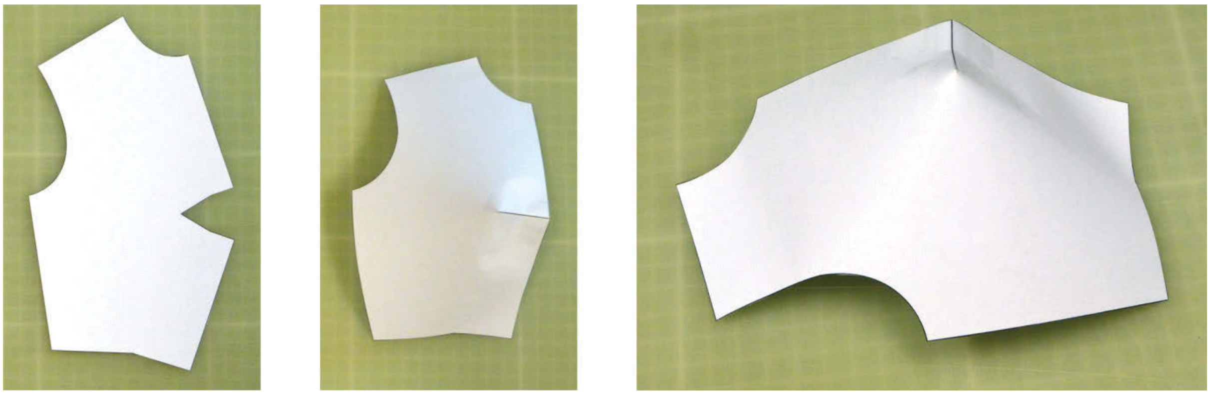
Figure 2: The tip of the cone of the dart is cut out because it creates an undesirable pointy shape. It is replaced by a new cone tip with a shape that can curve smoothly around bust point.



The flat pattern. | The pattern in 3D. | Side view of the pattern in 3D.

Model 10

Figure 3: The pattern is re-assembled and creates a dart which has the fit of the original block pattern, except that it avoids the undesirable pointed shape at bust point.



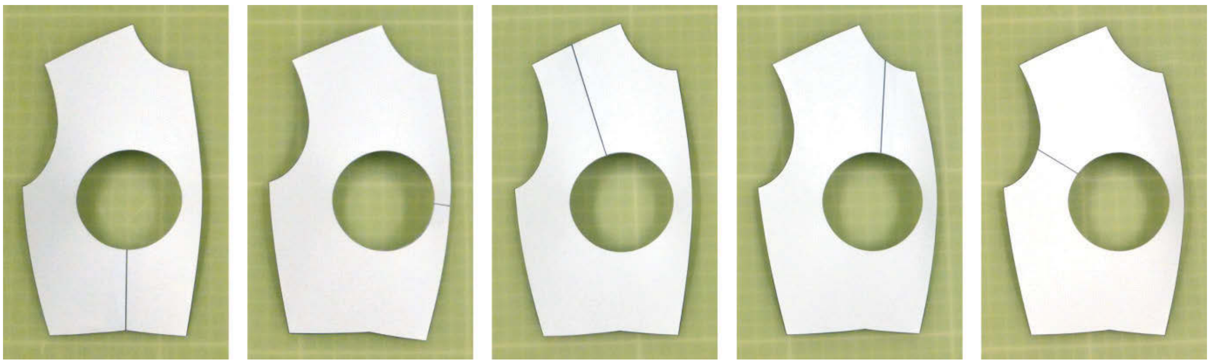
The flat pattern. The pattern in 3D. Side view of the pattern in 3D.

Model 11

Figure 4: The pattern is redrawn as a new pattern, creating the new bust point manipulation dart.

<u>Part 2</u>: Separately manipulating the base and tip of the cone

Set 2:



Model 12 Model 13 Model 14 Model 15 Model 16

Figure 5: A dart manipulation centred at bust point and cutting the cone off the top of the pattern, creates bases of the same three-dimensional form. This makes it easy to move the location of the dart to any position on the base of the pattern.

Set 3:

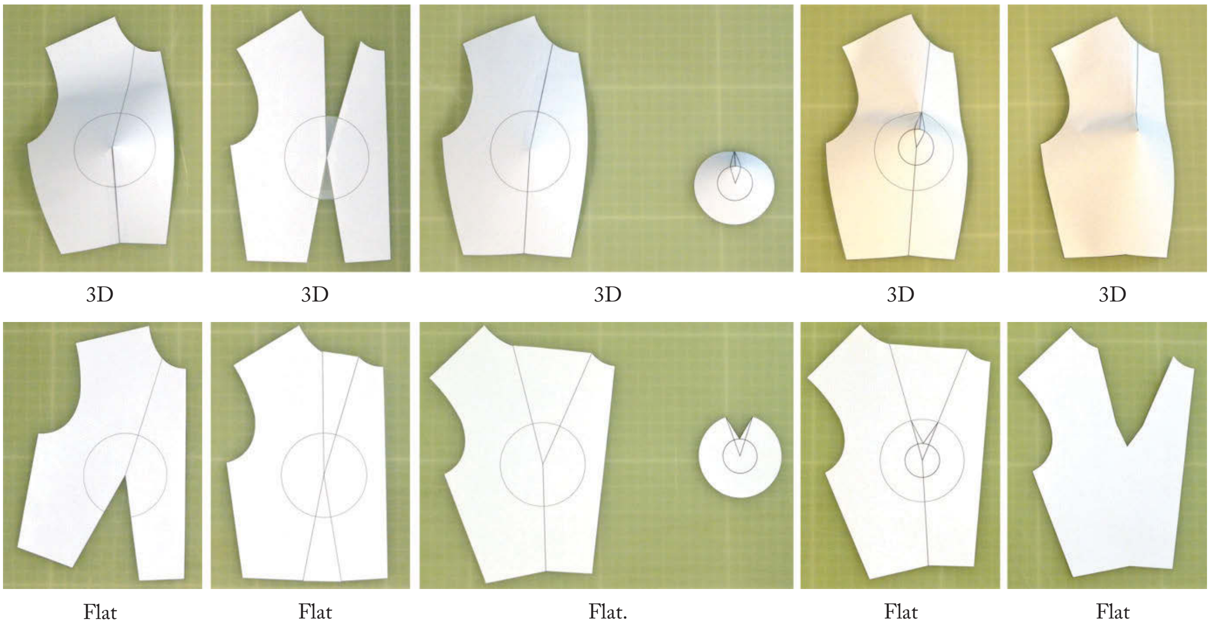
Model 17

Figure 6: The shaped cone placed on top of the pattern is rotated to the direction of the dart on the cone base. This cone maintains the surface area and volume as it simply rotates and does not change shape.

It is observed from this experiment that the tip of the cone can be rotated to many different locations, keeping the surface area and volume of the pattern while the dart apex moves. It is also see that the cone base with cone cut off can be easily manipulated using dart manipulation. Even though the cone tip is cut off, the pattern can still be manipulated, with its apex point at bust point.

Part 3:

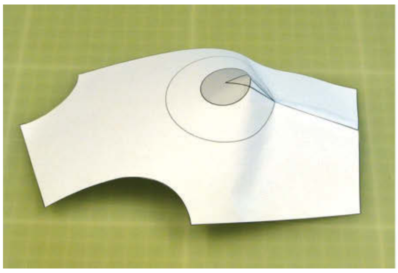
Set 4:



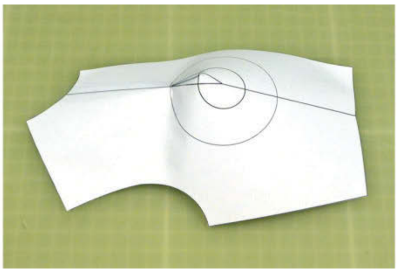
Model 18:	Model 19:	Model 20:	Model 21:	Model 22:
A new style line is drawn on the pattern.	The pattern is pivoted with the apex on bust point.	The cone on the top of the pattern is cut off and replaced with one that curves around bust point. It is rotated to face the direction of the dart.	The cone is attached to the base pattern, creating the new pattern.	The new pattern is redrawn and constructed in 3D.

Figure 7: The dart location is moved to a different position. The base pattern has its dart moved to a new location. The cone on the tip of the pattern is replaced with a cone that curves around bust point, which forms the new pattern.

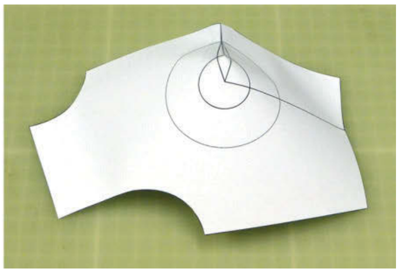
Set 5:



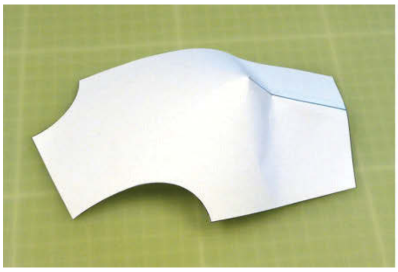
Showing darts and cone tip.



Showing darts and cone tip.



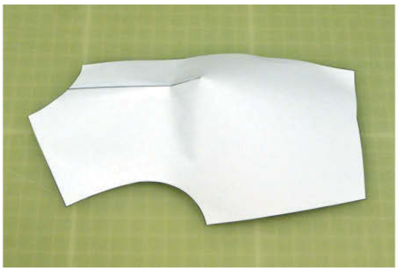
Showing darts and cone tip.



Model 23:

Final pattern.

The dart at the waist.



Model 24:

Final pattern.

The dart at the neck.

Model 25:

Final pattern.

The dart at the centre front.

Figure 8: The pattern with the dart at the centre front seam has the same fit, surface area and volume as the dart at the neck and the waist. These are essentially the same shape; the only difference is, the cone tip pattern has been rotated in a different direction.

It appears that these patterns have created a similar effect to traditional bust point manipulation. The dart apexes are moved away from bust point and seem to maintain the surface area and volume of pattern no matter where the dart is located. The only difference between traditional bust point manipulation and this alternative is that the dart angles are not straight lines. It may be possible to use a curved dart on the cone tip to create a desirable curved effect.

Conclusion

The experiment shows a process whereby it places the dart apex point in many different locations while maintaining the surface area and volume. Unlike traditional bust point manipulation, the base of the pattern and the cone tip are manipulated independently before being joined together.

Experiment 31: Testing Cone Tips of Different Shapes

Rationale

This experiment explores the different shapes of cone tip that can be used when moving the apex point of the dart around bust point. In the alternative technique to bust point manipulation the cone tip is replaced with a shape that smoothly curves around the bust. In previous experiments this has been a dart with straight edges that was moved away from bust dart. However, it is possible to have many types of curved dart. As the tips of the cone maintain a constant surface area and volume they can be any shape the patternmaker wants. The current experiment explores diverse possible shapes of cone tips.

Hypothesis

The research anticipates the creation of many cone tip shapes, all of which should be curved and smoothly contouring around the bust.

Experimental Design

The first part of the experiment outlines problems encountered with traditional bust point manipulation, notably the location of the dart changing the dart angle of the pattern and thus the final pattern. The second part examines the initial motivation for moving the dart apex in bust point manipulation. The third part examines the fit of the bust dart, and explores the idea of simply cutting off the dart tip and replacing it with a different-shaped pattern that blends to the body's contours. The final part combines these observations and offers an alternative to bust point dart manipulation.

Procedure

This experiment has two sets.

Set 1: Cone tips of different shapes

In the alternative to bust point manipulation the tips of cones with undesirable pointy shapes are replaced with new patterns that smoothly curve around the bust. These new cone tips have a dart that is off-centred from bust point. In previous experiments these darts are straight lines, but they may also be curved. The experiment thus explores cone tips of various shapes.

The cone tips are cone patterns centred at bust point, while the dart apex has been moved away from bust point. To illustrate this in the patterns, draw a circle shaded in grey to show the distance from bust point. The edges of the dart will also have to match up with the rest of the cone on the original pattern. The experiment creates three different-shaped cone tips and constructs them in new patterns.

Model 1: Draw a dart with straight edges on the cone tip.

Model 2: Draw a dart with a convex-shaped edge on the cone tip.

Model 3: Draw a dart with a concave-shaped edge on the cone tip.

Set 2: Cone tips of different shapes integrated into block patterns

The three different cone tips from set 1 will be integrated into block patterns. This creates an alternative bust point manipulation technique to create new patterns with the same fit.

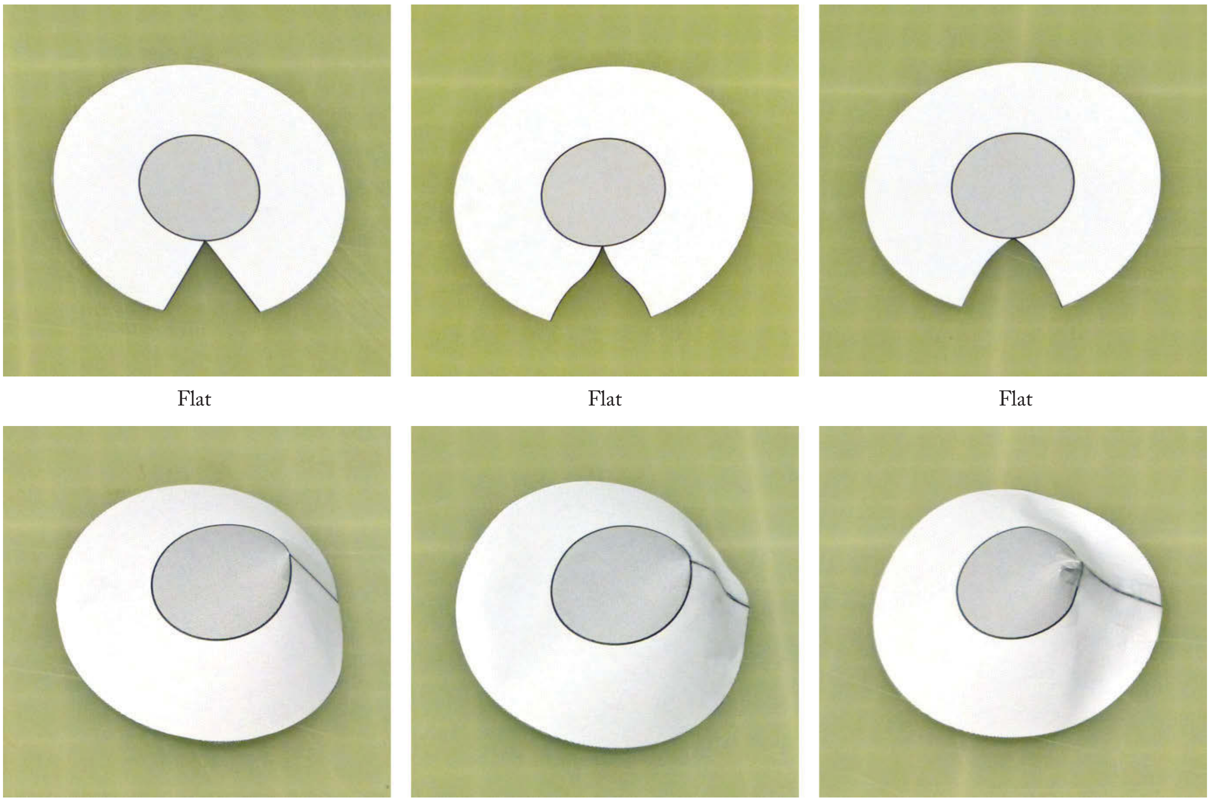
Model 4: Create a new pattern with a cone tip with straight edges (model 1). Create a 3D pattern and a flat pattern.

Model 5: Create a new pattern with a cone tip with convex-shaped edges (model 2). Create a 3D pattern and a flat pattern.

Model 6: Create a new pattern with a cone tip with concave-shaped edges (model 3). Create a 3D pattern and a flat pattern.

Results

Set 1: Cone tips of different shapes



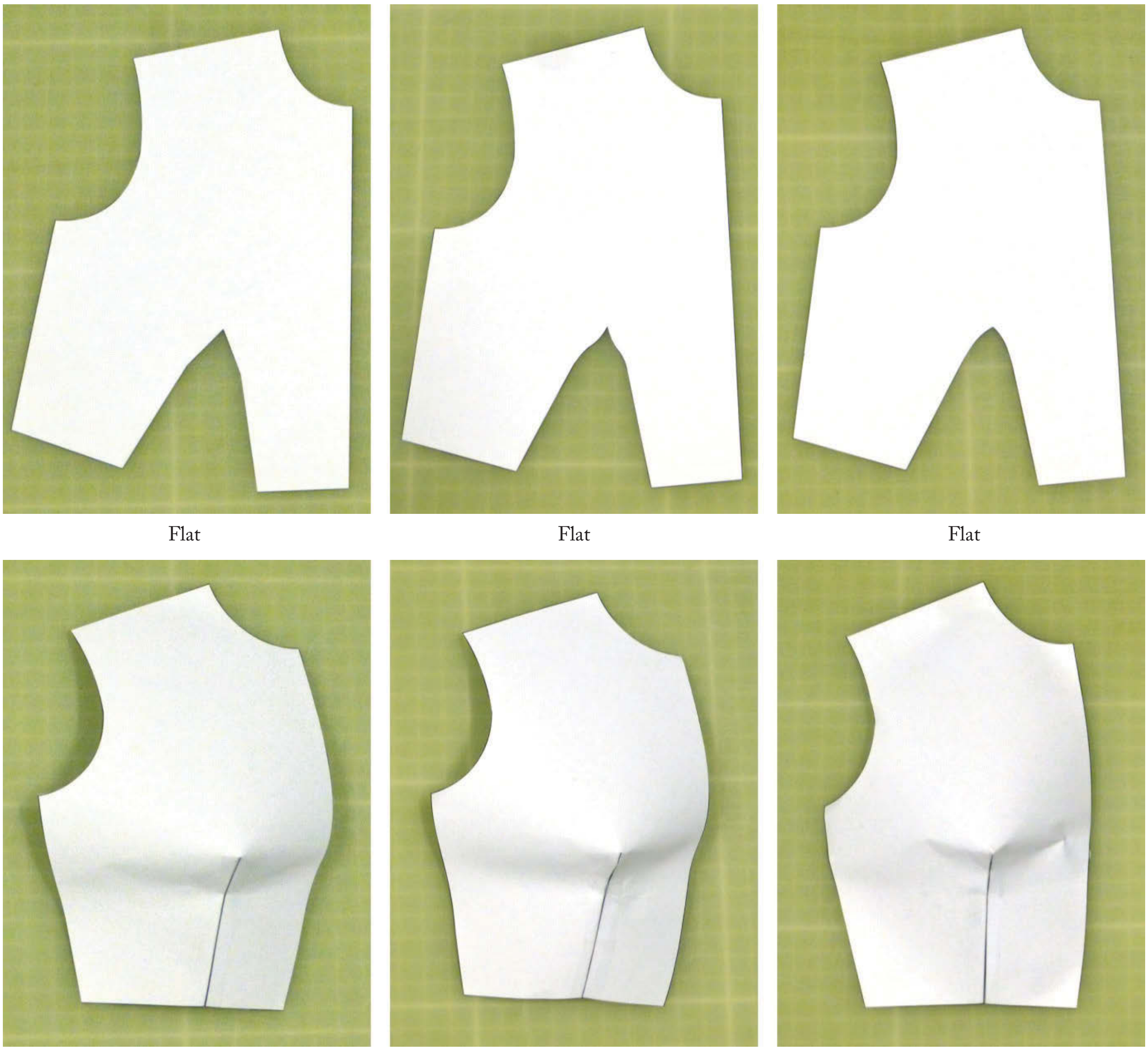
Model 1:
A cone tip with a straight edge.

Model 2:
A cone tip with a convex shape.

Model 3:
A cone tip with a concave shape.

Figure 1: Cone tips with different shapes can contour around the bust in many ways, giving designers new creative options while maintaining the fit of the garment.

Set 2: Cone tips of different shapes integrated into block patterns



Flat | Flat | Flat

3D | 3D | 3D

Model 4:
The pattern has a cone tip with a straight edge.

Model 5:
The pattern has a cone tip with a convex shape.

Model 6:
The pattern has a cone tip with a concave shape.

Figure 2: The cone tips determine the way the pattern contours around bust point, giving designers new creative options while maintaining the fit of the original garment.

It is noted that cone tips of different shapes create desirable-looking patterns that smoothly curve around bust point. Creating curved patterns offers patternmakers more creative options. The ability to rotate the cone tip as a way of moving apex points while maintaining the surface area, is also effective.

Conclusion

The experiment shows that it is possible to make cone tips of different shapes. They do not need to be darts with straight edges, but can also be curved. This is a great advantage for patternmakers as it is usually a problem to manipulate curved darts without forfeiting the fit of the garment. The technique allows dart apexes to be moved, and can easily manipulate cone tips with curved darts.

Experiment 32: An Alternative Method for Bust Point Manipulation with Multiple Darts

Rationale

This experiment demonstrates an alternative technique for bust point manipulation that allows multiple darts to be moved while maintaining the fit of the original garment. It creates a way of moving dart apexes around bust point while still maintaining the surface area and volume. It is used to manipulate a pattern with two darts and a pattern with three.

Hypothesis

The research anticipates the creation of a bust point manipulation technique that moves multiple apex points while maintaining the fit of the original garment.

Experimental Design

The experiment shows how to divide a single dart into multiple darts. This alternative to traditional bust point manipulation moves the apex locations around the tip of the bust while maintaining the pattern's surface area and volume. The first part divides a basic garment block into a pattern with two darts. The next set of iterations divides the basic garment block into three darts of different sizes, while the final part shows that different cone tips can be used to create patterns of diverse shapes. These patterns all move the dart apex while maintaining surface area and volume. It then tests them on patterns with two and three darts respectively.

Procedure

The pattern used scaled paper models that either remain flat patterns or are constructed in three dimensions. To ensure accuracy, the initial patterns are all printed from the same digital file on 80 gsm paper. It models what the flat and 3D patterns look like, making it easier to observe the techniques.

Set 1: Two darts

Model 1: Start with a basic block constructed in 3D. Draw a circle centred on bust point to define the tip of the cone of the pattern. Draw a red line from bust point to the right edge of the garment, to create the location of the new dart.

Model 2: Replicate model 1. Cut down the dart and flatten the pattern.

Model 3: Replicate model 1. Cut around the circle and remove the tip of the cone from the pattern.

Model 4: Replicate model 2. Cut down the red line and pivot the pattern to create two new darts.

Model 5: Replicate model 3. Replace the tip of the cone with a new cone tip. This cone tip has two different darts drawn to bust point. The cone must be replaced with a pattern in which the apex points have been moved away from bust point. Move the dart apexes an equal distance from bust point, then draw their dart legs so that they connect with the darts on the outside of the pattern. This pattern is described in detail in model 6 as a flat pattern.

Model 6: Trace model 4. The tip of the cone should be replaced with a pattern with apexes moved away from bust point. Move the apex points of both darts an equal distance away from bust point. In the circle, draw lines from the new apex points to the edges of the darts to form the new darts on the tip of the cone.

Model 7: Replicate model 5. Attach the cone tip to the pattern with tape.

Model 8: Redraw the flat pattern in model 6.

Model 9: Trace the outline of the pattern in model 8. Construct this pattern in 3D to create the final pattern with two darts.

Model 10: Replicate model 9 and cut down the darts to reveal the new flat pattern with two darts.

Set 2: Three darts

Model 11: Start with a basic block constructed in 3D. Draw a circle centred on bust point to define the tip of the cone of the pattern. Draw three red lines from bust point to the different edges to create the location of the new dart.

Model 12: Replicate model 11. Cut down the dart and flatten the pattern.

Model 13: Replicate model 11. Cut around the circle and remove the tip of the cone from the pattern.

Model 14: Replicate model 12. Cut down the red lines and pivot the pattern to create three new darts.

Model 15: Replicate model 13. Replace the tip of the cone with a new cone tip. This tip has three different darts drawn to bust point. The cone must be replaced with a pattern in which the apex points have been moved away from bust point. Move the dart apexes an equal distance from bust point, then draw their dart legs so that they connect with the darts on the outside of the pattern. This pattern is described in greater detail as a flat pattern in model 6.

Model 16: Trace model 14. The tip of the cone should be replaced with a pattern with apexes moved away from bust point. Move the apex points of both darts an equal distance away from bust point. In the circle draw lines from the new apex points to the edges of the darts to form the new darts on the tip of the cone.

Model 17: Replicate model 15. Attach the cone tip to the pattern with tape.

Model 18: Redraw the flat pattern in model 16.

Model 19: Trace the outline of the pattern in model 18. Construct this pattern in 3D to create the final pattern with three darts.

Model 20: Replicate model 19 and cut down the darts to reveal the new flat pattern with three darts.

Set 3: Curved cone tip darts

This iteration shows how cone tips with curves of different shapes can be used to replace the tip of the cone. These patterns can be rotated and will retain surface area and volume. The location of the darts can also be moved around the pattern by pivoting the dart around the pattern. In short, it can move the location of the apex but the pattern will retain surface area and volume.

This example takes a block pattern with two darts. The cone tip has two darts with straight edges. These straight darts accompany darts with curved edges in order to give the cone tip a better fit at bust point.

Model 21: Start with the flat pattern from model 8. On the tip of the cone erase the straight edge darts and draw curved edge darts to the apex points. Make sure the curved darts are symmetrical so that they can easily fit together. Do this for both darts. This creates a new cone tip with a curved-edged dart.

Model 22: Trace model 21 and cut out the darts.

Model 23: Construct model 22 as a 3D model using tape.

Set 4:

This iteration takes a block pattern with three darts. The cone tip has three darts with straight edges. These straight darts accompany darts with curved edges in order to give the cone tip a better fit at bust point.

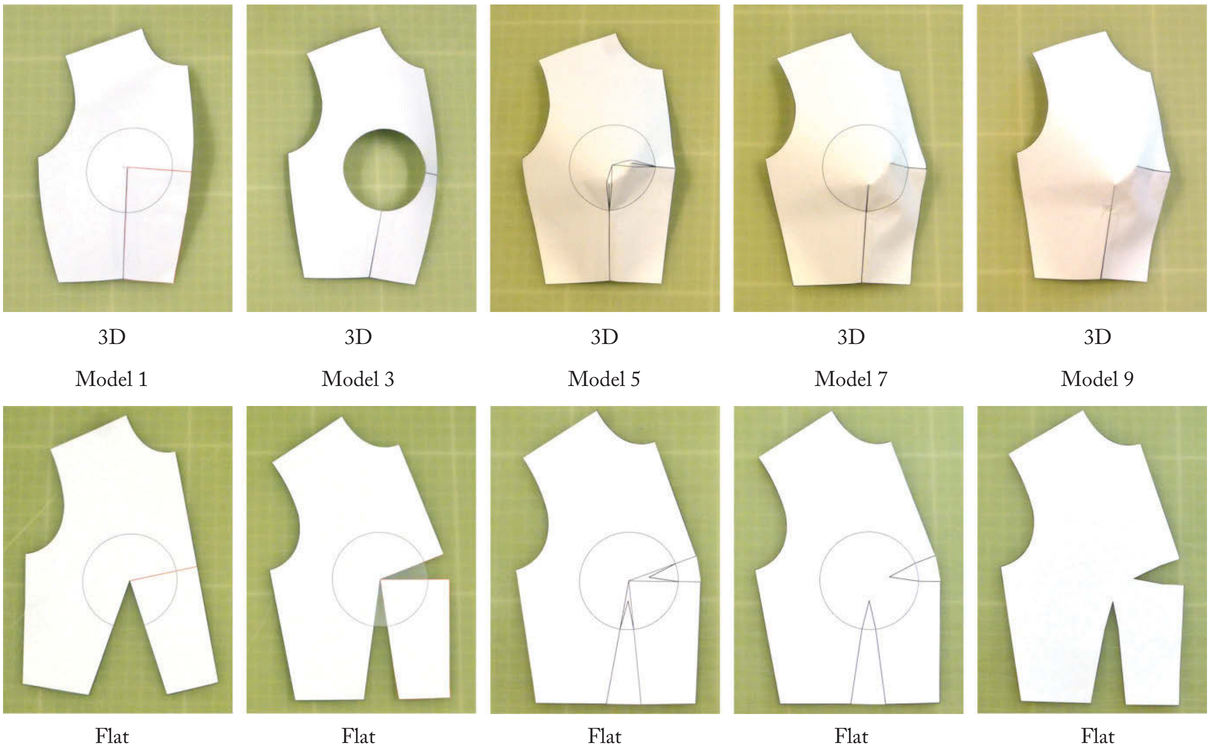
Model 24: Start with the flat pattern from model 18. On the tip of the cone erase the straight edge darts and draw curved-edge darts to the apex points. Make sure the curved darts are symmetrical so that they can easily fit together. Do this for all three darts. This creates a new cone tip with a curved-edged dart.

Model 25: Trace model 24 and cut out the darts.

Model 26: Construct model 25 as a 3D model using tape.

Results

Set 1: Two darts



Model 2:
The new locations of the dart are designed on the pattern.

Model 4:
The pattern is pivoted at bust point creating the two new darts.

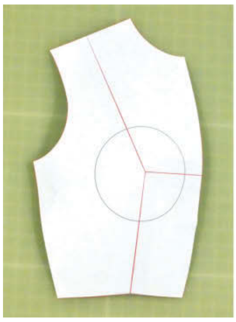
Model 6:
A cone tip is then created that will curve around bust point.

Model 8:
This new cone tip is attached to the garment.

Model 10:
The final pattern is redrawn and constructed in 3D.

Figure 1: This technique allows a patternmaker to create multiple darts on a pattern while maintaining the fit and creating a contoured shape around bust point. In this example a pattern with two darts is created.

Set 2: Three darts



3D

Model 11

3D

Model 13

3D

Model 15

3D

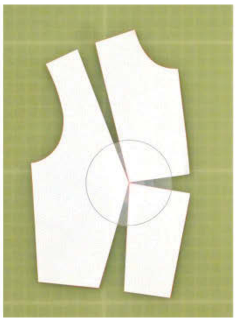
Model 17

3D

Model 19

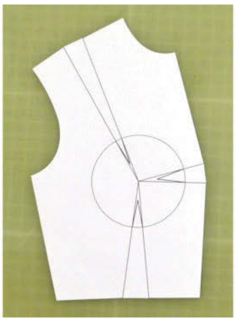
Flat

Model 12:
The new locations of the dart are designed on the pattern.



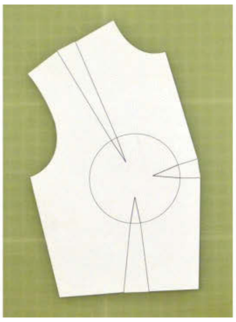
Flat

Model 14:
The pattern is pivoted at bust point creating the three new darts.



Flat

Model 16:
A cone tip is then created that will curve around bust point.



Flat

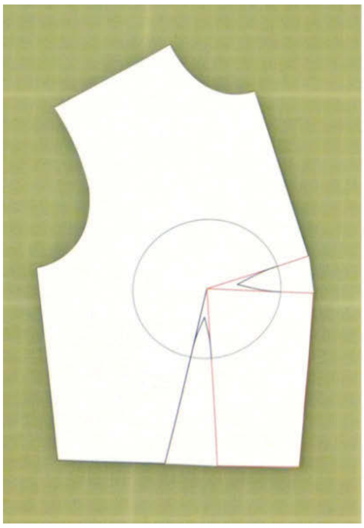
Model 18:
This new cone tip is attached to the garment.

Flat

Model 20:
The final pattern is redrawn and constructed in 3D.

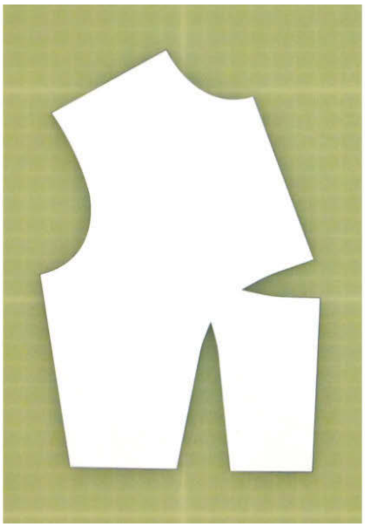
Figure 2: This technique allows a patternmaker to create multiple darts on a pattern while maintaining the fit and creating a contoured shape around bust point. In this example a pattern with three darts is created.

Set 3: Curved cone tip darts



Flat.

Model 21:
The cone tip is curved to create a contoured shape around bust point.



Flat

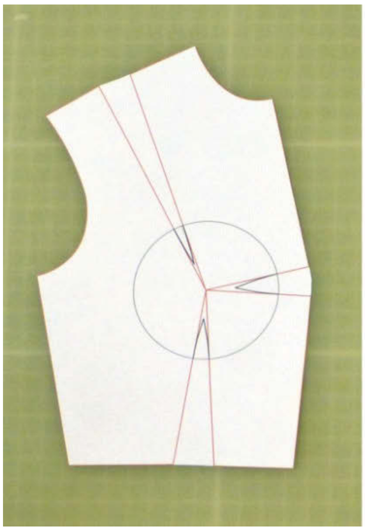
Model 22:
The new dart is re-drawn as a flat pattern.

3D

Model 23:
The 3D pattern with two curved darts.

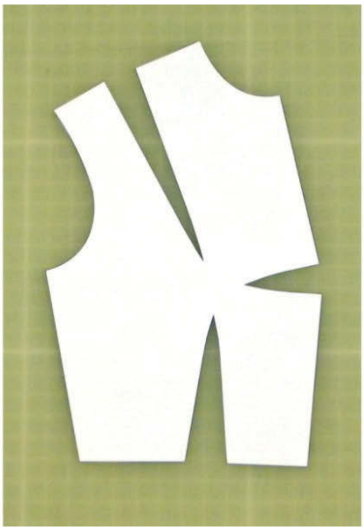
Figure 3: On a pattern with two darts, the tip of the cone can be curved to shape the garment around bust point.

Set 4:



Flat

Model 24:
The cone tip is curved to create a contoured shape around bust point.



Flat

Model 25:
The new dart is re-drawn as a flat pattern.

3D

Model 26:
The 3D pattern with three curved darts.

Figure 4: On a pattern with three darts, the tip of the cone can be curved to shape the garment around bust point.

Conclusion

The experiment shows how it can move multiple darts around bust point while maintaining a pattern with a similar fit, surface area and volume.

9. Creative Patterns Inspired by Geometry

Experiment 33: **Achieving more creative patterns using geometry**

Experiment 34: **Achieving greater complexity with more apex points**

Experiment 35: **Greater creative freedom with fewer apex points**

Experiment 36: **Modifying patternmaking and drape techniques for easier patternmaking**

Aim

These four experiments explore different ways in which learning from geometric principles can inspire different approaches to patternmaking. By understanding how all shapes can be comprised of combinations of Euclidean, spherical and hyperbolic geometry, it is possible to design complex shapes and deconstruct them into flat patterns. One approach looks at how patterns with more apex points deliver patterns with more detail. Another explores the ways draping patterns with fewer apex points can give a patternmaker more creative freedom to draw style lines. It is also possible to use contour manipulation to design very intricate style lines on a garment while maintaining the original geometric fit.

Method

The first experiment presents a method whereby a designer can build a shape in their imagination by combining different primary shapes. The designer's ability to identify shapes as Euclidean, spherical or hyperbolic makes it easier to deconstruct them into flat patterns. The second experiment examines ways that asymmetrical darts and contours can create patterns with more apex points and greater complexity. The third experiment looks at how creating patterns with fewer apex points can give patternmakers greater control when designing style lines, in that they are enabled to draw more intricate patterns. The final experiment drapes a pattern in a way that deliberately creates fewer apex points, making it easier to apply contour manipulation to the pattern. This technique lets us create a complex style line on a pattern that maintains geometric equivalence with the original garment.

Analysis

These experiments take inspiration from geometry and find applications for them in patternmaking. Some of the approaches are counter-intuitive to traditional patternmaking yet still give effective results. The understanding that any 3D shape is either: Euclidean, spherical or hyperbolic in its geometry makes it much easier for patternmakers to create flat patterns of complex shapes. For example: it is possible to take a flower, build it out of primary shapes, then deconstruct it into a flat pattern.

It also explores how asymmetrical darts and gussets create complex shapes with more apex points than symmetrical patterns. Subsequent experiments show that to deliberately create a pattern with fewer apex points makes it easier to design style lines on a garment. Using contour manipulation, it notes that the more apex points are drawn, the more points the style lines must pass through. Fewer apex points means that there is more creative freedom to draw different-shaped style lines. It demonstrates this by draping a contoured dress block pattern with fewer apex points, making it easier to draw a complex style line on the pattern while maintaining the geometric equivalence of the original.

Experiment 33: Achieving More Creative Patterns Using Geometry

Rationale

This experiment constructs a complex pattern from the designer's imagination using Euclidean, spherical and hyperbolic shapes. It seeks to take a complex three-dimensional shape and deconstruct it into a series of simple geometric shapes. Understanding the types of patterns created by different types of geometry should make it easy for designers to develop patterns for complex shapes.

Hypothesis

The research anticipates that it can take a complex three-dimensional shape and deconstruct it into a series of simpler pieces.

Experimental Design

The experiment takes a flower design and deconstructs it into smaller primary shapes. Patternmakers should be familiar with how to turn basic geometric shapes into flat patterns (see figure 1). They should also be able to identify the structure's spherical, hyperbolic or Euclidean geometry (see figure 2), so that once the design has been deconstructed into primary shapes they can create a flat pattern to simulate the structure.

Procedure

All the patterns are illustrated as three-dimensional objects and as flat patterns.

Model 1: Start with a design for a three-dimensional flower shape. The flower should have a stem, leaves, ruffled petals and large spherical stigma in the centre of the flower (refer to figure 3 for the illustrated model and figure 4 for the paper model).

Model 2: Analyse the structure of the flower. Observe which parts of the pattern are spherical, hyperbolic or Euclidean in their geometry. Deconstruct the pattern into smaller pieces (refer to figure 3 for the illustrated model and figure 4 for the paper model).

Model 3: Deconstruct each component of the pattern into a three-dimensional shape. Then deconstruct that pattern into a flat pattern (refer to figure 5 for the illustrated model and figure 6 for the paper model).

The stigma of the flower is a sphere and can be flattened into a series of lune shapes.

The style of the flower is a cone and can be flattened into a circle with a dart.

The ruffled petals are a hyperbolic shape and can be created by joining several gussets together.

The leaves are flat Euclidean surfaces but they curve in the centre of the leaf. They can be created by joining two flat Euclidean surfaces together and having a contoured seam line run down the centre of the leaf.

Model 4: Generate the flat patterns from model 3 and construct a three-dimensional model of the flower (refer to figure 7 for the illustrated model and figure 8 for the paper model).

Model 5: Now that the patternmaker is familiar with the three-dimensional shape it is even possible to use contour manipulation to move the locations of the style lines and create different versions of the flower pattern (refer to figure 7 for the illustrated model and figure 8 and 9 for the paper model).

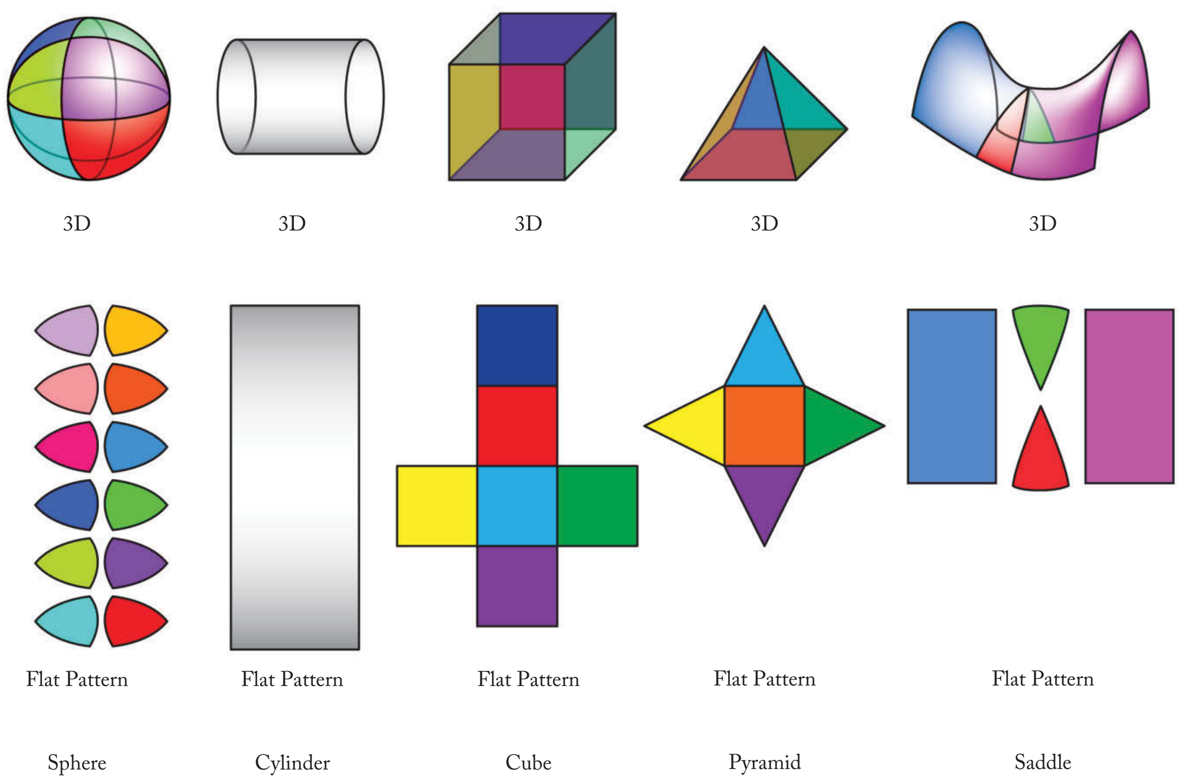


Figure 1: Different geometric shapes can be deconstructed into flat patterns.

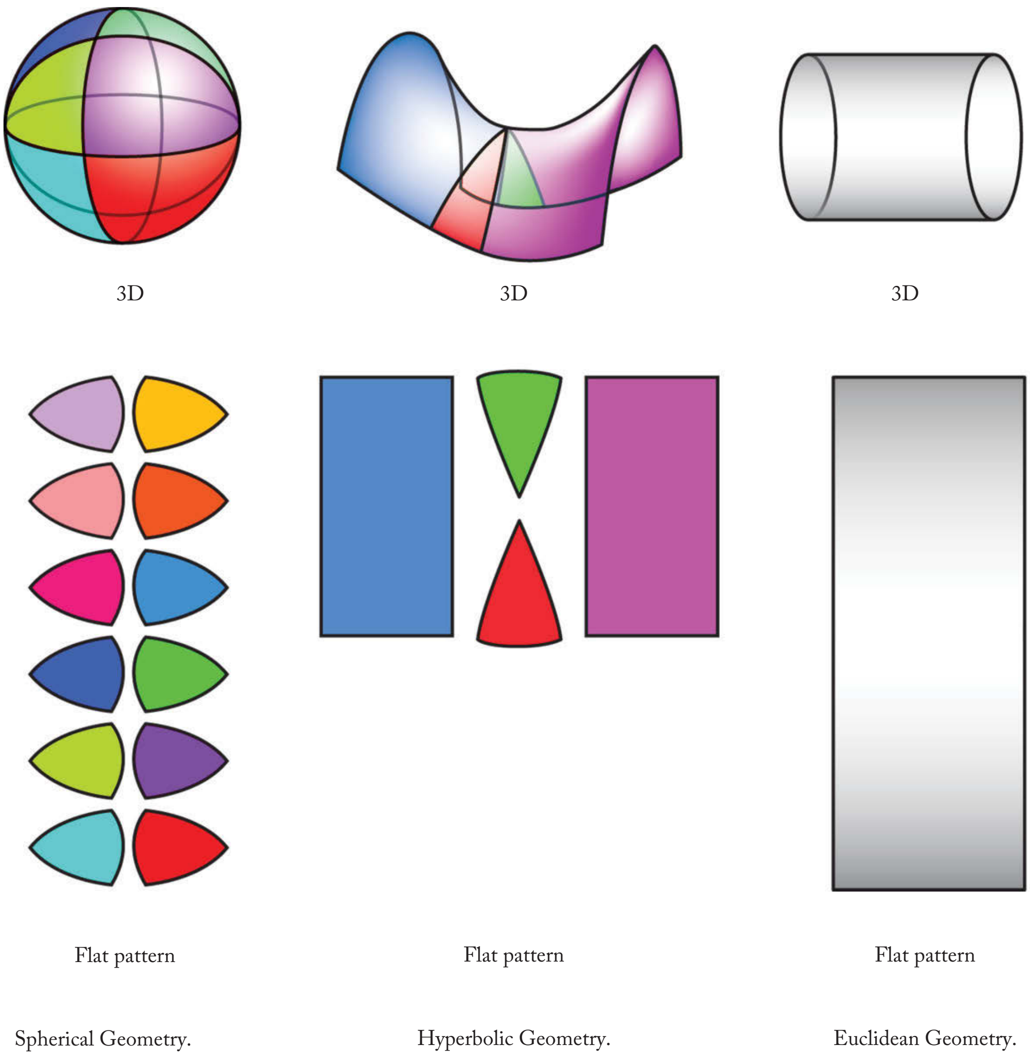
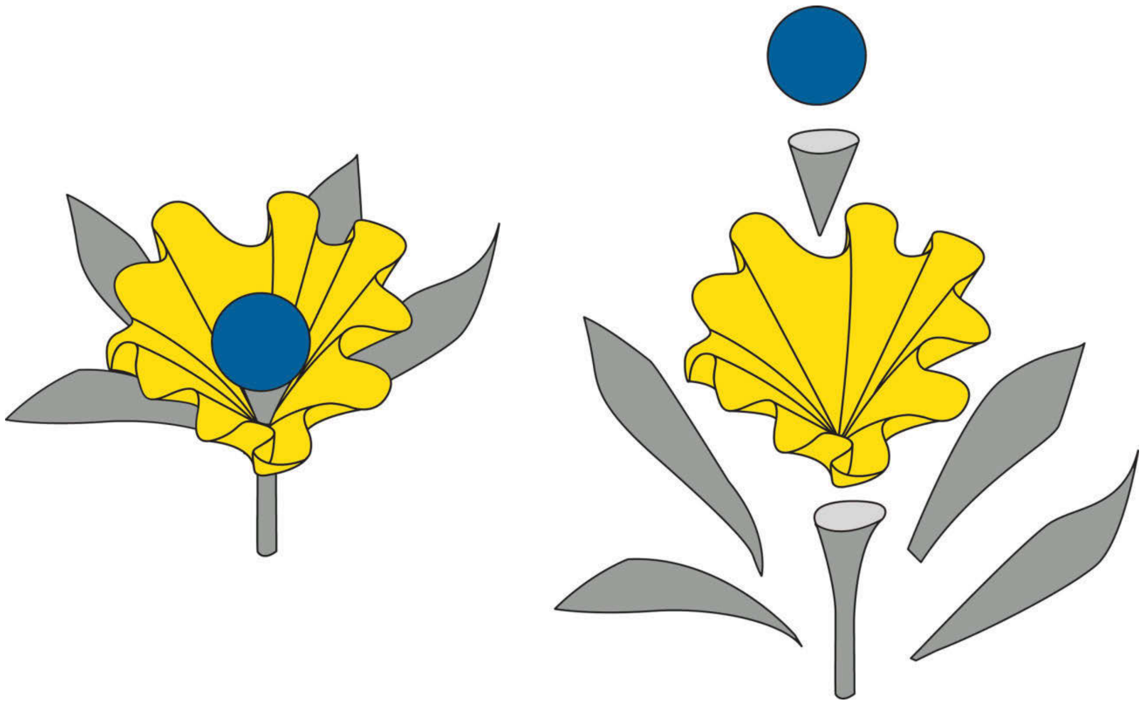


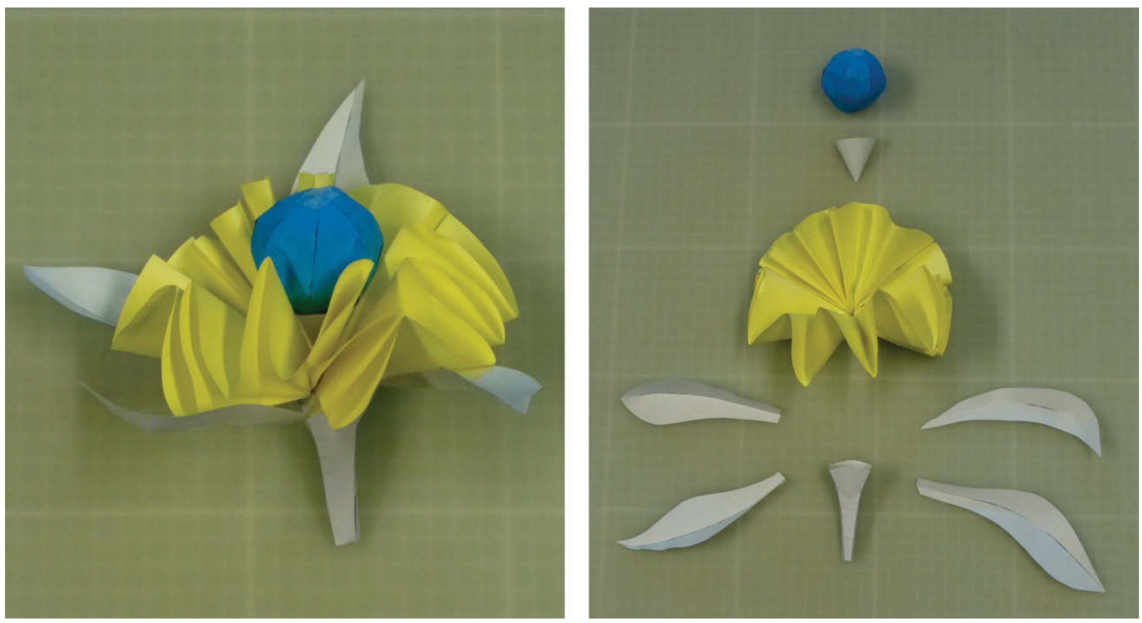
Figure 2: Three-dimensional shapes flattened.

Results



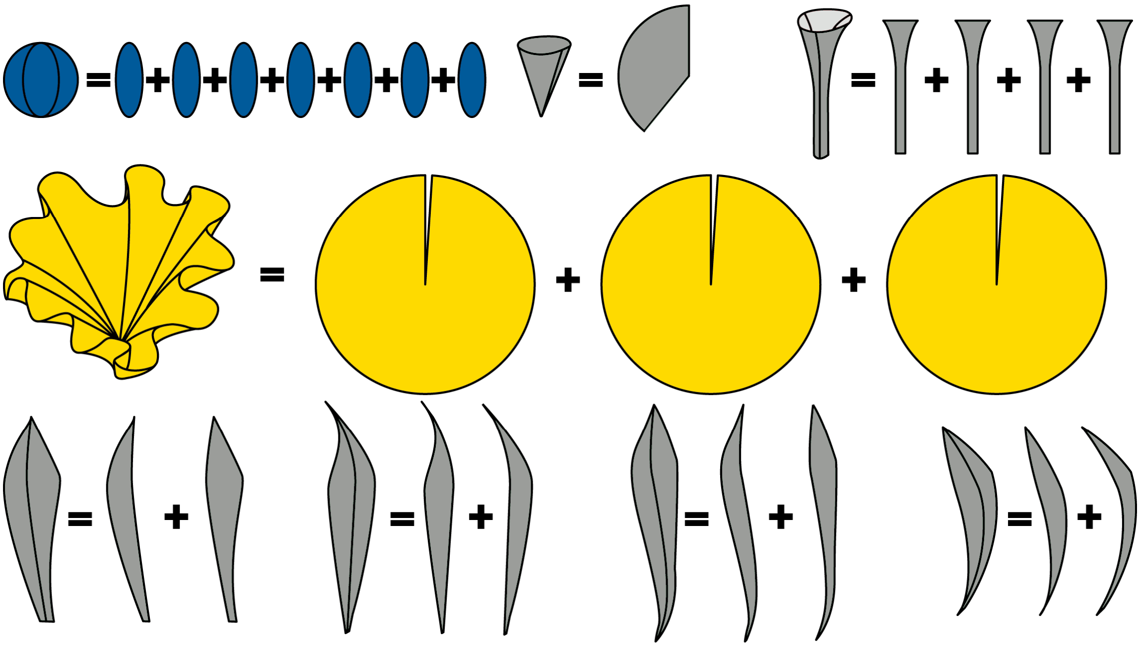
Model 1 Model 2

Figure 3: A sculpture of a flower can be constructed out of basic geometric patterns.



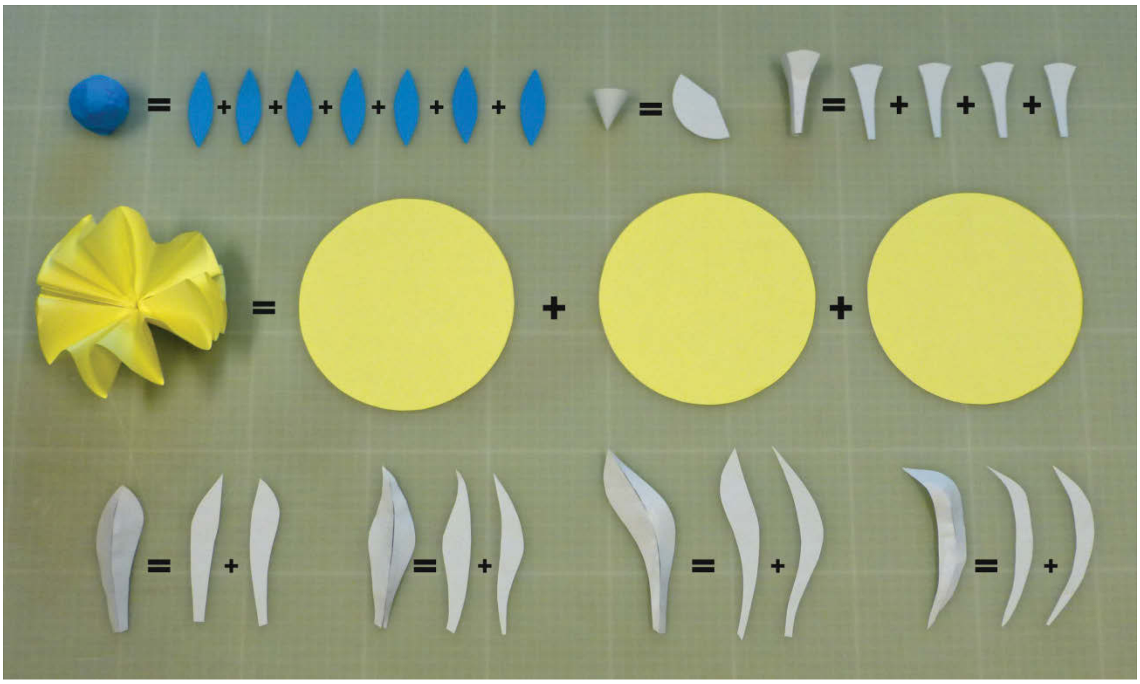
Model 1 Model 2

Figure 4: Paper model of the flowers from **Figure 3.**



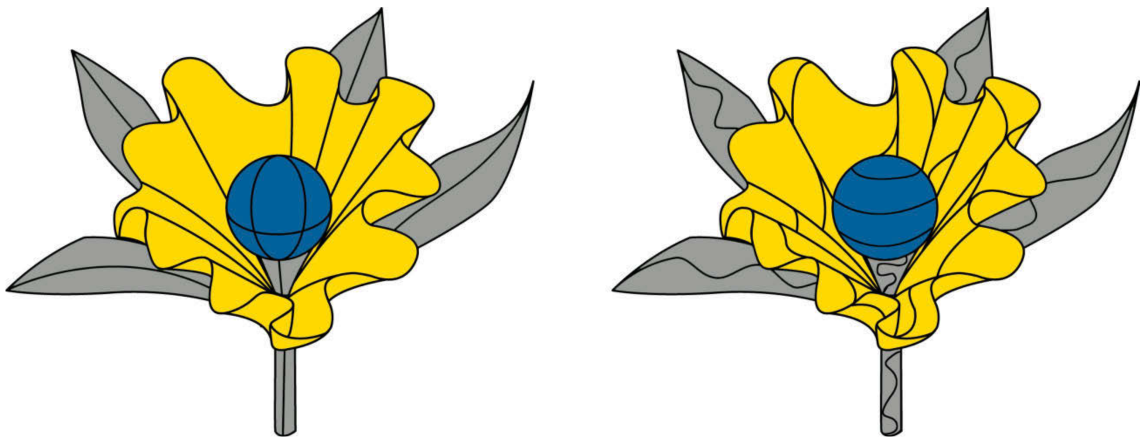
Model 3

Figure 5: The different geometric pattern shapes can be deconstructed into flat patterns.



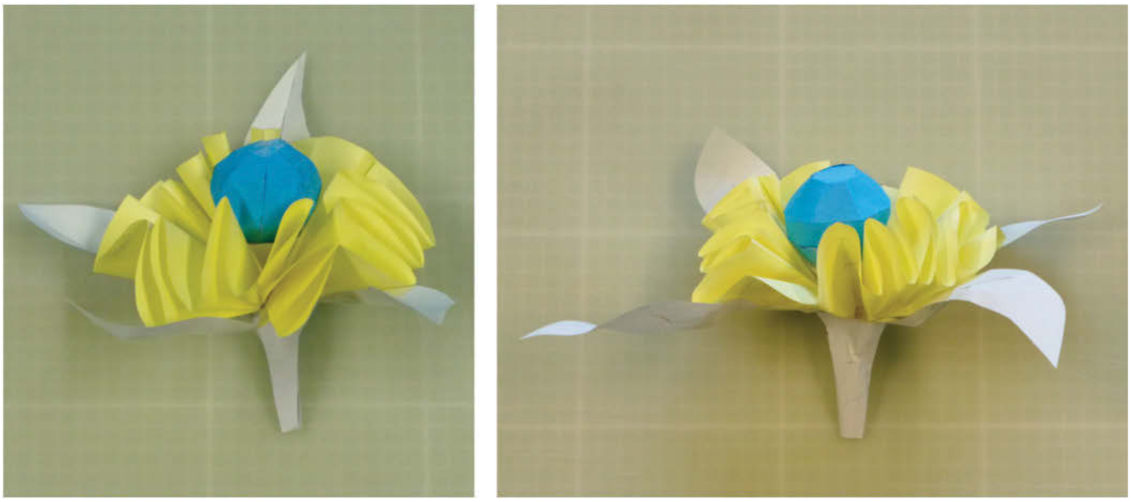
Model 3

Figure 6: Paper model of geometric shapes from **Figure 5.**



Model 4 Model 5

Figure 7: The flower models have the same three-dimensional shape but different style lines.



Model 4 Model 5

Figure 8: Paper models of flowers in **Figure 7.**

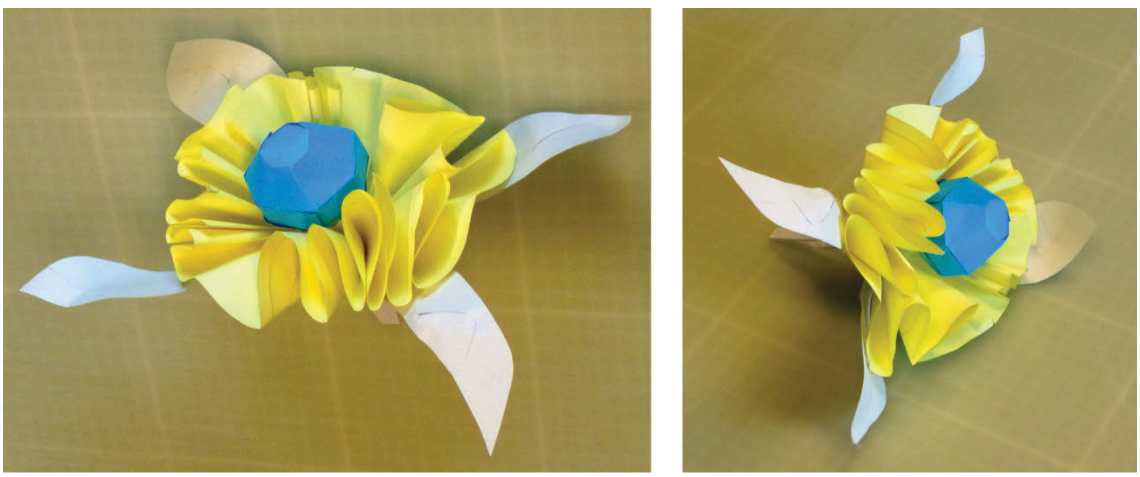


Figure 9: Different views of model 5. The flower has the same three-dimensional form with style lines in different locations.

Conclusion

The experiment shows that when patternmakers are familiar with the underlying geometry that governs patternmaking they should be able to take any complex three-dimensional shape and deconstruct it into a series of smaller, less complex shapes.

Experiment 34: Achieving Greater Complexity with More Apex Points

Rationale

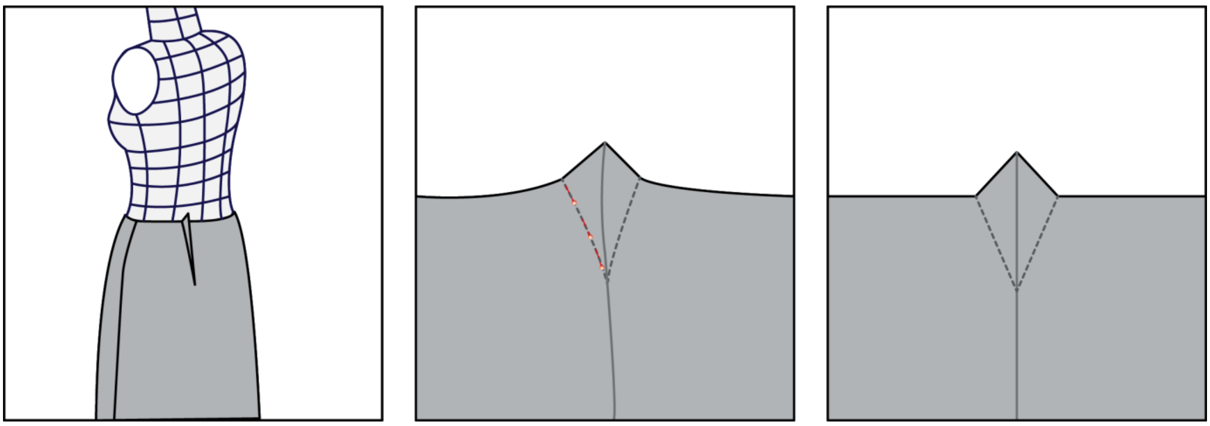
This experiment demonstrates that by creating asymmetrical patterns, there are more sites for apex points. For patternmakers it is an intuitive approach to create symmetrical patterns when draping on a mannequin or drafting a pattern on paper, yet asymmetrical patterns may present more opportunities to shape the fabric. Through two sets of iterations it shows that asymmetrical darts offer more apex points than symmetrical ones.

Hypothesis

The research anticipates that by creating asymmetrical darts there will be more sites for apex points.

Experimental Design

This experiment shows that asymmetrical darts can hold more apexes than symmetrical darts, and can thereby shape the pattern in greater detail. When draping fabric on a mannequin (see figure 1) patternmakers intuitively drape symmetrical patterns. If using pins to create a pattern it tends to create a symmetrical dart. The experiment draws several symmetrical darts and compares them to asymmetrical ones. The number of apex points is then counted.



Draping on a mannequin. Patternmakers pin garments. Pins create symmetrical shaped patterns.

Figure 1: Patternmakers draping fabric on a mannequin tend to create symmetrical shapes, due to pins being used on the fabric.

Procedure

The first iteration of this experiment observes the structure of darts while the second looks at the properties of diamond-shaped asymmetrical darts.

Set 1:

These patterns are drawn as flat patterns, following which the amount of apexes are counted.

Model 1: Create a straight edge dart on rectangular pattern.

Model 2: Create a dart with two apex points that has mirror symmetry. Circle the apexes in blue and use a dotted red line to show where the apex point attaches.

Model 3: Create a dart with three apex points that has mirror symmetry. Circle the apexes in blue and use a dotted red line to show where the apex point attaches.

Model 4: Create an asymmetrical dart where one side is straight and the other leg has two apexes. Circle the apexes in blue and use a dotted red line to show where the apex point attaches.

Model 5: Create an asymmetrical dart where both dart legs have two apexes but whereby the location of the apexes does not align. Circle the apexes in blue and use a dotted red line to show where the apex point attaches.

Model 6: Create an asymmetrical dart where both dart legs have three apexes but whereby the location of the apexes does not align. Circle the apexes in blue and use a dotted red line to show where the apex point attaches.

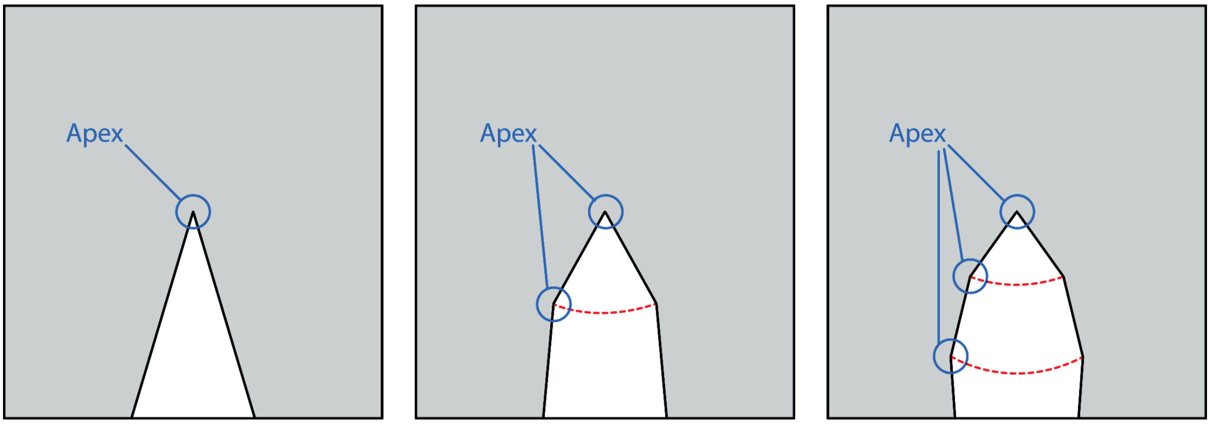
Set 2:

Model 7: Create a diamond shaped dart. Circle the apexes in blue and use a dotted red line to show where the apex point attaches.

Model 8: Create an asymmetrical diamond shaped dart with one apex on the left side and two apexes on the right side. Circle the apexes in blue and use a dotted red line to show where the apex point attaches.

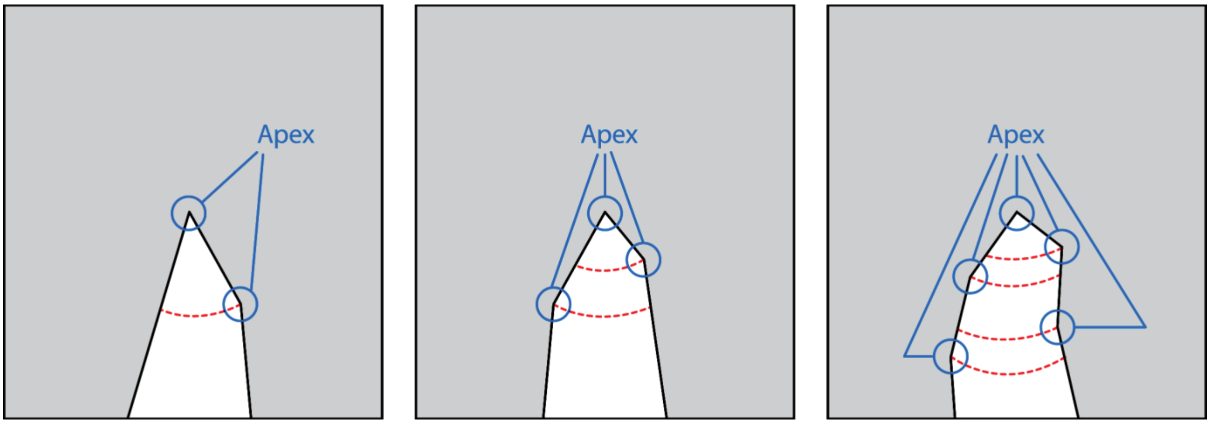
Model 9: Create an asymmetrical diamond shaped dart with three apexes on each side, but with their apexes aligning at different locations. Circle the apexes in blue and use a dotted red line to show where the apex point attaches.

Results



Model 1 Model 2 Model 3

Symmetrical darts create a limited number of apex points.



Model 4 Model 5 Model 6

Asymmetrical darts offer more apex points because their asymmetry creates more locations for apex points.

Figure 2: Asymmetrical darts can hold more apex points than symmetrical darts, allowing them to shape the contours of the body with greater control.

It is observed that when darts are asymmetrical they create more locations for apex points.

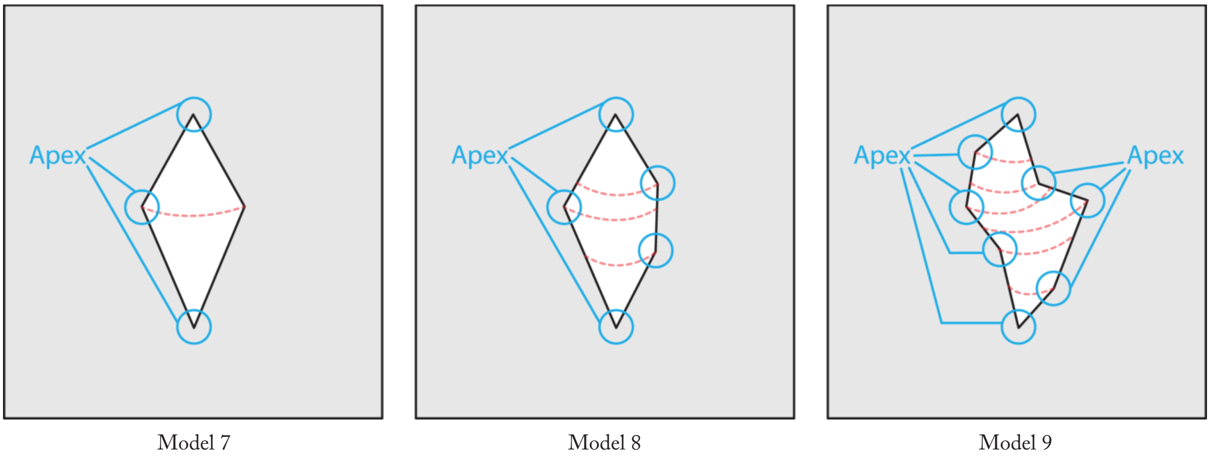


Figure 3: Diamond-shaped darts can also have asymmetry. The more apex points, the more the garment can be shaped.

Conclusion

The experiment shows that asymmetrical darts offer more sites for apex points, and that this applies to both darts and diamond-shaped darts. It is observed that asymmetrical darts or contours have the opportunity to shape a pattern with greater detail, suggesting that draping garments with more complex asymmetrical patterns may be a more efficient way of manipulating a garment.

Experiment 35: Greater Creative Freedom With Fewer Apex Points

Rationale and Hypothesis

This experiment explores the idea that creating patterns with fewer apex points gives the designer more freedom to create a wider range of design lines. With contour manipulation a curved line can be broken down into a series of straight lines. The smoother the curve, the more apex points are created. However, the more apex points on a curve, the more apex lines a designer must draw through to keep the original design shape when using contour manipulation. This reduces the amount of creative freedom the designer has to draw different shapes. The experiment tests the idea of deliberately creating a pattern with fewer apex points in order to give the designer greater freedom when designing style lines. When draping patterns, designers seek create patterns with smooth edges. The technique takes the counter-intuitive approach of creating a pattern that has a desirable fit but employs a series of straight lines instead of a continuous curve.

Experimental Design

This experiment compares the use of smooth curved lines to patterns made from a series of straight lines. It compares the contour lines and apex points of each pattern. Through a series of iterations, it compares patterns with many apex points to patterns with fewer points, testing the ability of the designer to draw creative style lines on the pattern. To do so, draft a pattern with fewer apex points and test it.

Procedure

The experiment consists of three parts. The patterns are drafted on a computer program and visual observations are made. The same process can be tested with physical models of garments. The second part of the experiment examines how contour manipulation can be used to deconstruct curves into a series of straight lines. Patternmakers may interpret a curved line with different levels of geometric accuracy. It tests what happens when they deliberately drape a line with fewer apex points yet still get an acceptable fit.

Part 1:

Set 1:

The first part of the experiment analyses a smooth curved line on the side seam of a skirt block pattern. It identifies the apex points on the curve and drafts a style line on the pattern.

Model 1: Start with a basic skirt block pattern. Identify the apex points on the pattern.

Model 2: Using contour manipulation the curved side seam of the garment is deconstructed into a series of straight lines and apex points.

Model 3: Draw a new style line that passes through all the apex points.

Make observations about these patterns.

Part 2:

The second iteration examines how contour manipulation can be used to deconstruct curves into a series of straight lines. Patternmakers may interpret a curved line with different levels of geometric accuracy. It tests what happens when they deliberately drape a line with fewer apex points yet still get an acceptable fit.

Set 2:

Model 4: Start with a curved seam line pattern.

Model 5: Using the same pattern from model 4, use contour manipulation to turn the curve into a series of straight lines and apex points.

Make observations about these curves.

Set 3:

Model 6: Recreate the curve from model 5 and identify the apex points in red.

Model 7: Recreate the curve from model 4. This time, redraw the curve with longer tangent lines. This pattern should be less accurate than the original curve, but offer fewer apex points.

Make observations about these curves.

Set 4:

This experiment tests a pattern with a normal curve to a pattern that is deliberately draped with fewer apex points. Creating a curve with fewer apex points does change the pattern shape, so the patternmaker should make sure it still has an acceptable fit.

Model 8: Drape the side seam of a skirt block using a smooth curved seam line.

Model 9: Observe the number of apex points created by this pattern.

Model 10: Deliberately drape a seam line on the side of the pattern. This is a series of straight lines instead of a smooth curved line. The seam should still be draped to fit the body with an acceptable fit. The pattern will have fewer apex points than a curved seam line.

Model 11: Observe the number of apex points create in model 10.

<u>Part 3</u>:

The third iteration tests patterns that have been deliberately created with fewer apexes so that it is possible to draw style lines with more creative freedom.

Set 5:

Model 12: Re-create model 9 (the pattern with a curved seam line). Draw a curved style line that passes through all the apex points.

Model 13: Re-create model 11 (the pattern with less seam lines). Draw a curved style line that passes through all apex points.

Make observations on the amount of freedom the designer has to draw style lines in each of these patterns.

Set 6:

This part of the experiment explores the creative options of a seam line with fewer apex points.

Model 14: Recreate model 11. Identify the number of apex points in the pattern.

Model 15: Observe the configuration of apex points in model 14 and plan a style line that will pass through each apex point.

Model 16: Draw a style line that passes through all the apex points in the pattern.

Make observations on the amount of freedom the designer has to draw style lines in each of these patterns.

Results

Part 1:

Set 1:

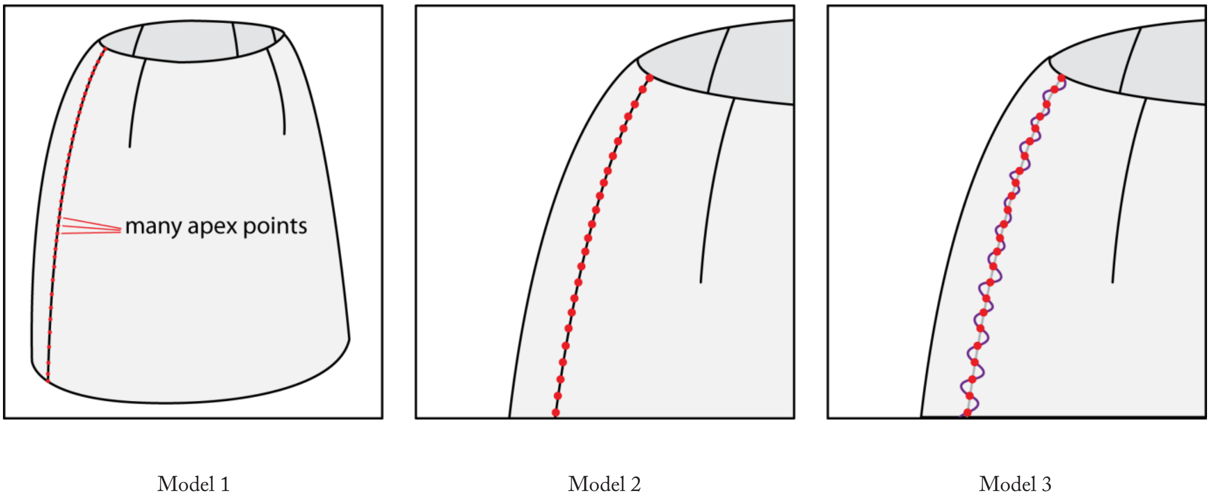
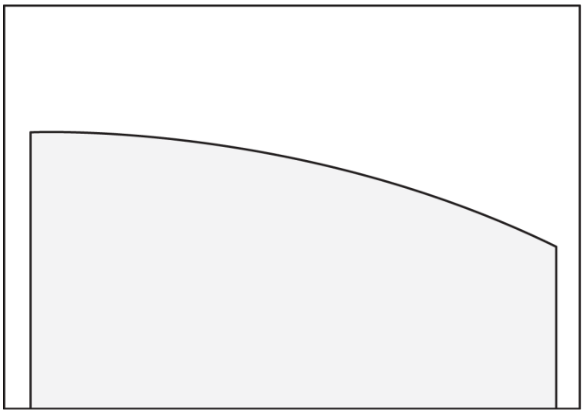


Figure 1: The difficulty of using contour manipulation on a curved seam line is that it has multiple apexes. In order to maintain geometric equivalence, it must draw through all of the apex points. Having so many apex points limits the patternmaker's creative freedom.

It is observed that curved seam lines create many apex points.

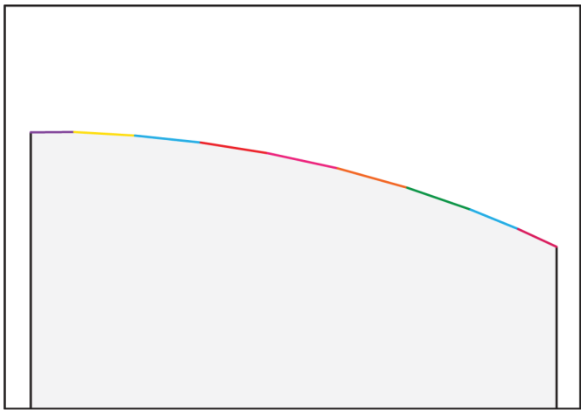
Part 2:

Set 2:



Model 4:

A curved line on a pattern.



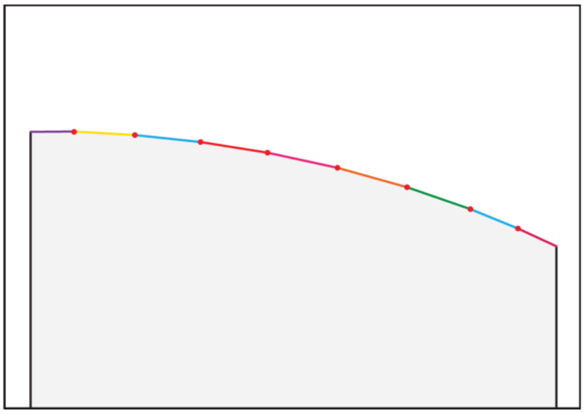
Model 5:

A curved line broken into a series of straight tangent lines on a pattern.

Figure 2: It is difficult to distinguish between the pattern of a curved line and a pattern that is a series of tangents.

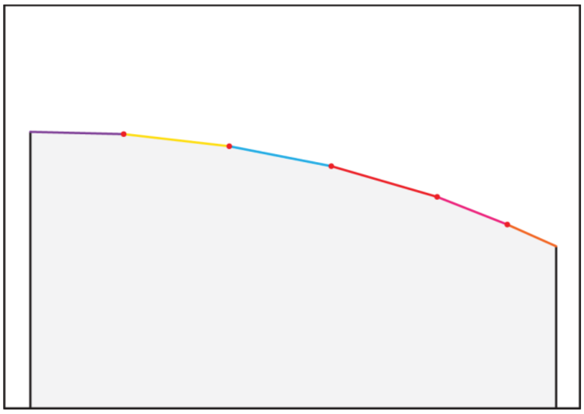
It is observed that contour manipulation translates a curved seam line into a series of straight lines and apex points.

Set 3:



Model 6:

A curve with shorter tangent lines will have greater apexes.



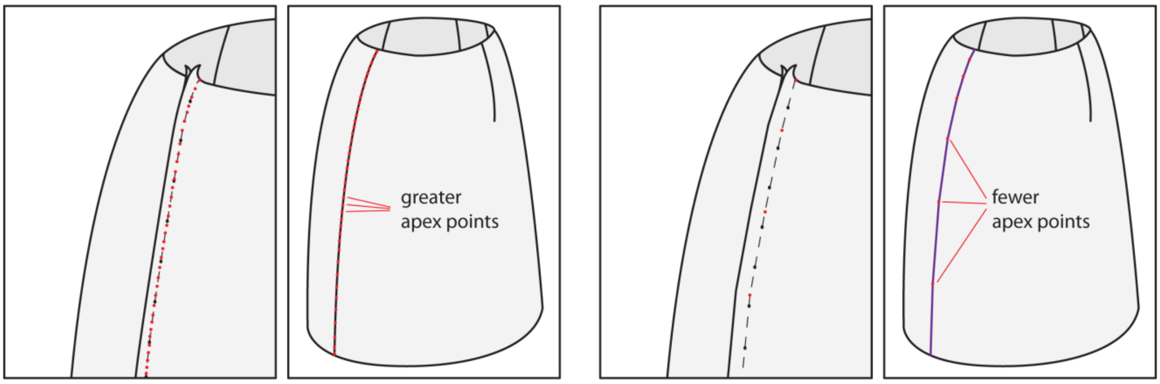
Model 7:

A curve with longer tangent lines will have fewer apexes.

Figure 3: A patternmaker can interpret a curved line into a series of apexes with different levels of detail.

It is noted that with contour manipulation a curved seam line can be interpreted into a series of straight lines with different levels of detail. Straight tangent lines of a shorter length are better able to describe complex curves. Alternatively, creating longer tangent lines creates fewer apex points, but it loses some of the detail of the curve. Still, the patternmaker can drape a pattern with an acceptable fit and fewer apexes, offering them the creative freedom to design style lines on a pattern with fewer apex points.

Set 4:



Model 8:
A smooth curve creates patterns with many apex points.

Model 9:
A pattern with many apex points makes it difficult to re-shape the curve, as the style line must pass through every apex.

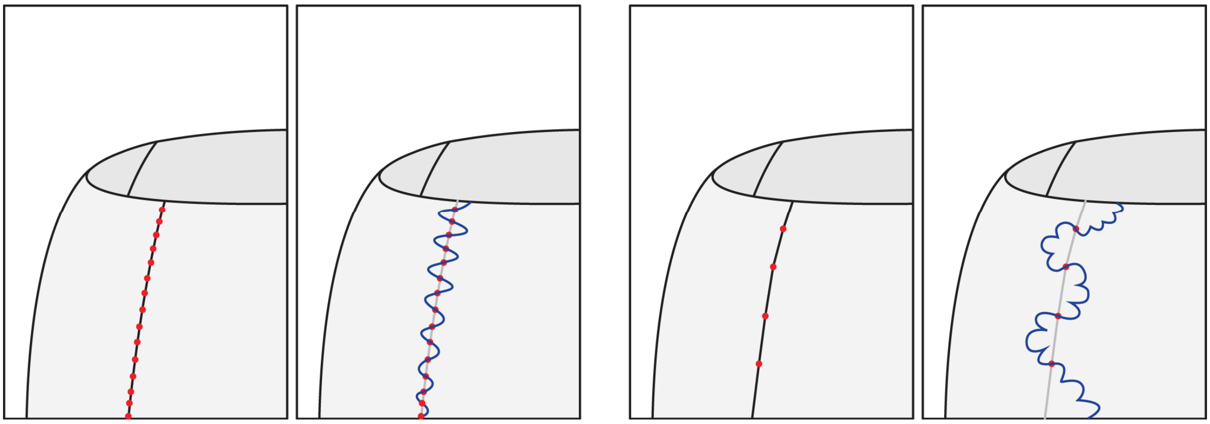
Model 10:
It is possible to deliberately create a pattern with a desirable fit which fewer apex points.

Model 11:
A pattern with fewer apex points gives a patternmaker greater creative freedom when designing style lines.

Figure 4: This pattern has been draped to reduce the number of apexes, making it easier to modify using contour manipulation. If the number of apexes is reduced to an extreme, the pattern may even be a slightly different shape to the original garment.

Part 3:

Set 5:



Model 12:

Greater numbers of apexes give a patternmaker less creative freedom to draw style lines.

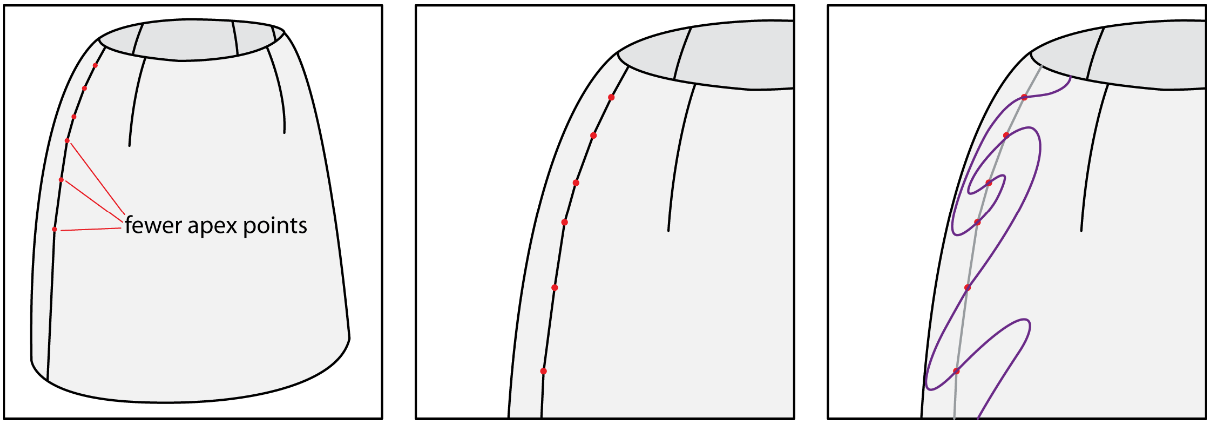
Model 13:

Fewer apexes give a patternmaker greater creative freedom to draw style lines.

Figure 5: Fewer apexes gives patternmakers greater creative freedom to draw style lines.

A pattern with more apex points offers very little freedom, as there are so many points that the shape of the seam line tends to dictate the pattern shape. A pattern with fewer apex points gives the patternmaker more space to draw style lines, wherein the shape of the style line is dictated less by the shape of the curve.

Set 6:



Model 14:

Patternmakers can deliberately reduce the number of apex points.

Model 15:

Fewer apex points make patterns easier to manipulate with contour manipulation.

Model 16:

Fewer apex points gives designers greater freedom to design exotic shapes.

Figure 6: The fewer the apex points in a curve, the more freedom there is to draw any design while maintaining geometric equivalence.

Conclusion

This experiment shows that it is possible to deliberately drape a pattern with fewer apex points and still have an acceptable fit. The research offers the patternmaker greater freedom to create extremely intricate patterns without the loss of geometric accuracy as long as the style lines pass through the apex points. In this iteration the pattern is so intricate that the sewing of the pattern becomes complex and time-consuming. It offers thereby, an extreme case for the sake of testing the technique to its limits. A faster technique may be just to reduce the number of apexes in the part of the garment that it wishes to manipulate.

Experiment 36: Modifying Patternmaking and Drape Techniques for Easier Patternmaking

Rationale

This experiment demonstrates that by making slight modifications to a basic block pattern, it can create extremely complex patterns without losing geometric accuracy. The experiment relies on contour manipulation and is based on the principle that complex curves can be deconstructed into a series of straight lines. By deliberately draping a pattern involving a series of straight lines instead of a single continuous curved line, it is easier to define the apex points of the pattern. This in turn makes it easier to use contour manipulation, allowing the patternmaker to create complex patterns without losing geometric accuracy.

Hypothesis

The research anticipates that by creating a pattern that is a series of straight lines instead of a single straight line, it can use contour manipulation to create very complex patterns without losing geometric accuracy. This should allow us to create a pattern with the exact shape and fit of the original garment. It should anticipate that even though the pattern has the geometric shape of the original, when constructed in fabric it will create a pattern with grain lines that point in different directions. This may change the behaviour of the fabric, depending on the properties of the material.

Experimental Design

The experiment has three parts. The first part uses contour manipulation on a curved contour pattern, interpreting the smooth curves into a series of straight lines and apex points. However, these straight lines still have a geometric form almost indistinguishable from the original pattern. In the second part of the experiment a complex pattern is designed on the garment. The style line of the pattern passes through each apex point, maintaining the geometric equivalence of the original pattern. This pattern will then be cut down the style lines, forming a new curved pattern. In the experiment's third part the front block of a pattern is sewn together. Due to the complex design, it is time-consuming to sew, so that to demonstrate the concept only the front part of the garment is sewn together. The new pattern with curved style lines is then compared with the original pattern with curved style lines.

Procedure

The experiment is in three parts. The first part takes a contoured pattern of a dress and uses contour manipulation to deconstruct the curved contours into a series of straight lines and curves. The straight lines follow the edges of the pattern so that the pattern with straight lines is almost indistinguishable from the one with curved lines.

Set 1:

Model 1: Start with a contoured pattern of a dress. This is a size 10 dress block which is stored as a digital file.

Model 2: Take the pattern from model 1 and apply contour manipulation so that all the curved lines are deconstructed into a series of straight lines.

The straight lines follow the edges of the pattern so that the pattern with straight lines is almost indistinguishable from the pattern with curved lines.

Model 3: Observe model 1 in detail and observe how the pattern is continuously curved.

Model 4: Observe model 2 in detail. Observe how the pattern is a series of straight lines. Yet with the scale of the pattern, the straight lines make up the same shape as the original.

Set 2:

Now that all the patterns have been deconstructed into a series of straight lines and apexes, draw a curved style line that passes through all the apex points. This ensures that the original pattern and the new pattern will be geometrically equivalent.

Model 5: Take the pattern from model 2 and translate the pattern into a paper pattern. Draw a curved style line on the pattern that will pass through each apex point. This allows the patternmaker freedom to design extremely complex curved patterns. The pattern is a series of straight seam lines instead of a continuous curved seam line. This means that as long as the style lines pass through the apex points all the patterns that join together are straight edges.

Model 6: This shows in detail the curved design from model 5.

Model 7: This shows a detailed view of model 5. The pattern shows the seam line that joins two patterns together. The curved seam lines are a series of straight lines, which means that when the edges are joined together they attach without a loss of accuracy. In this model, curved seam lines in semi circles are cut between the apex points. They can be cut out and attached to the other side of the pattern.

Set 3:

Models 8, 9 and 10 demonstrate the way the pattern maintains geometric equivalence using a diagram. In each of the patterns, a line between the apex points is straight. This means that two straight lines can be joined to each other without losing accuracy. If the patterns were curved lines and they joined together, the curve of the patterns would be lost.

Model 8: This diagram shows two pattern pieces that join together. The style lines are designed in red. A dotted red line is shown of two parts of the pattern that will be cut out and attached to the neighbouring pattern. These are located on the bottom left pattern and the middle of the right pattern.

Model 9: Recreate model 8 and cut the patterns with dotted lines out of the patterns. Move them to attach to their corresponding spot on the neighbouring pattern. The patterns perfectly fit together as their edges are straight lines and they are of the same length.

Model 10: Recreate model 9. Attach the two pattern pieces to their corresponding patterns. This neatly creates a new pattern.

Make observations about this process.

Set 3:

Model 11: This is the entire pattern of model 5 when it has been cut down the style line and the pattern pieces have been joined together.

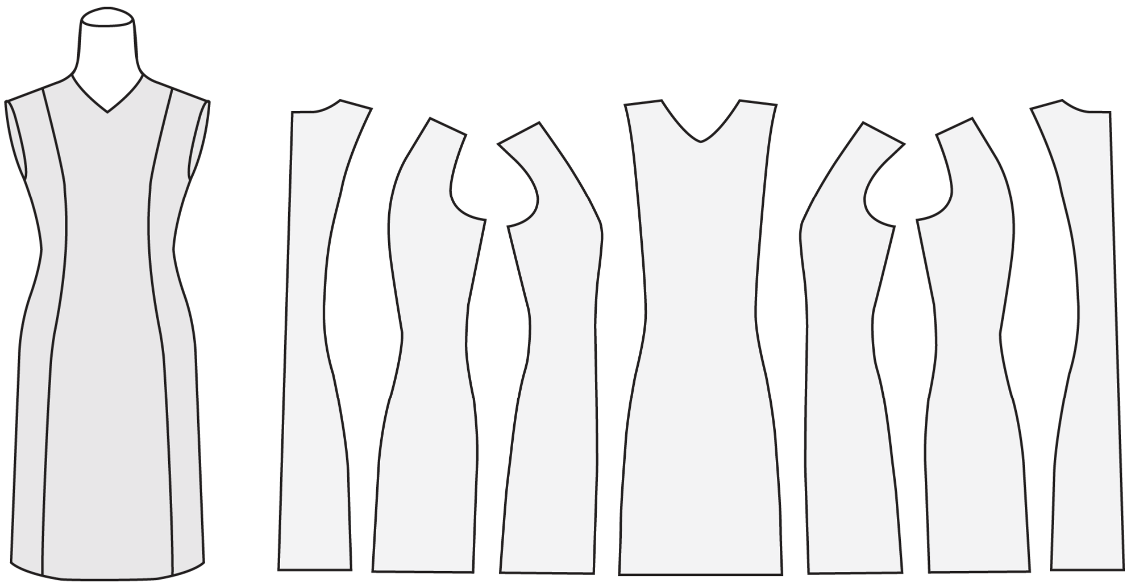
This pattern is time-consuming to sew because of its complex curves. The pattern for the front block of the pattern is taken and sewn together. The front block is chosen as it has the most complex curvature. It also compares the fit of the pattern by draping the front pattern of the original on top of the new pattern.

Model 12: This is the original pattern from model 1 draped on top of a mannequin.

Model 13: This is the front block of the new pattern draped on top of the front block on a mannequin.

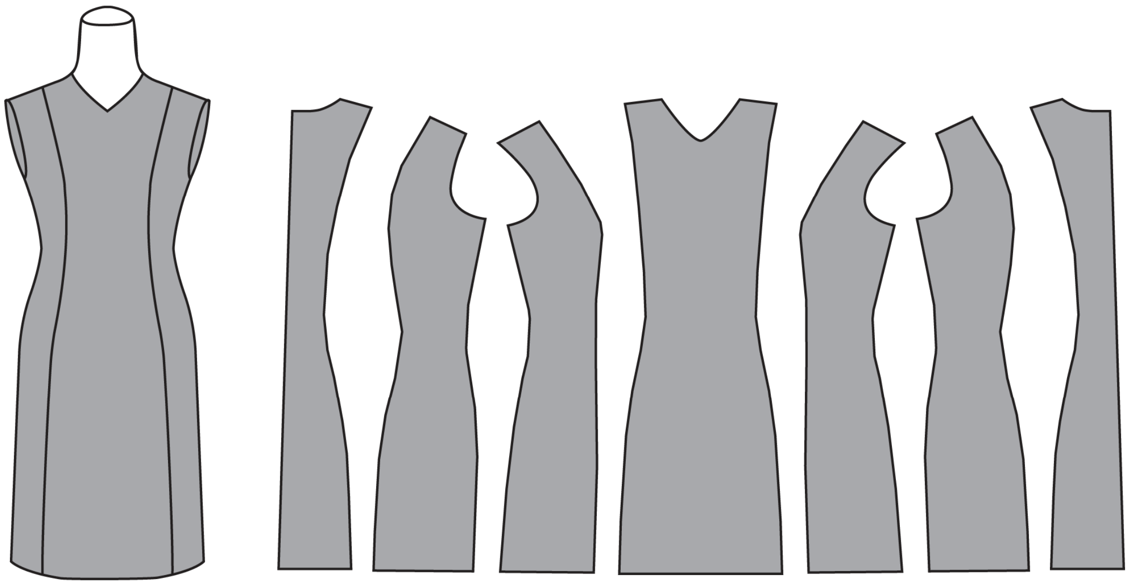
Results

Set 1:



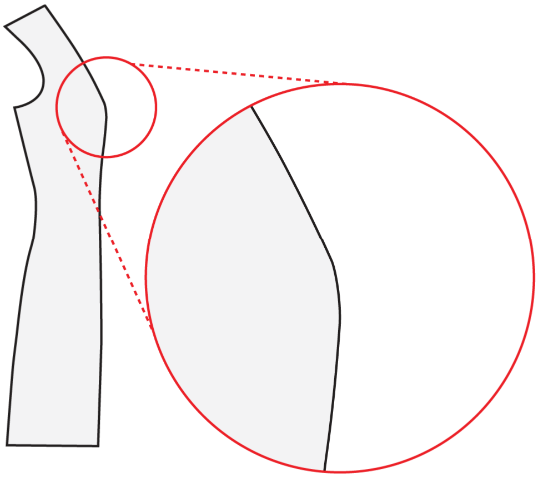
Model 1

Figure 1: A conventional pattern with curved contours draped on a mannequin.



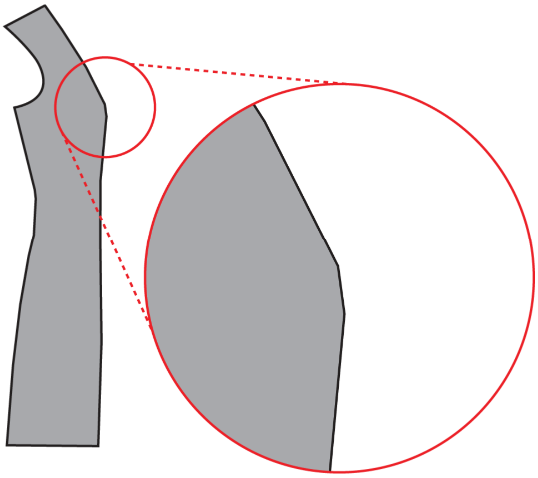
Model 2

Figure 2: A pattern that has been deliberately draped so that the contours are a series of straight lines instead of curved. This pattern is visually indistinguishable from a pattern with curved lines.



Model 3:

Pattern draped with curved edges.



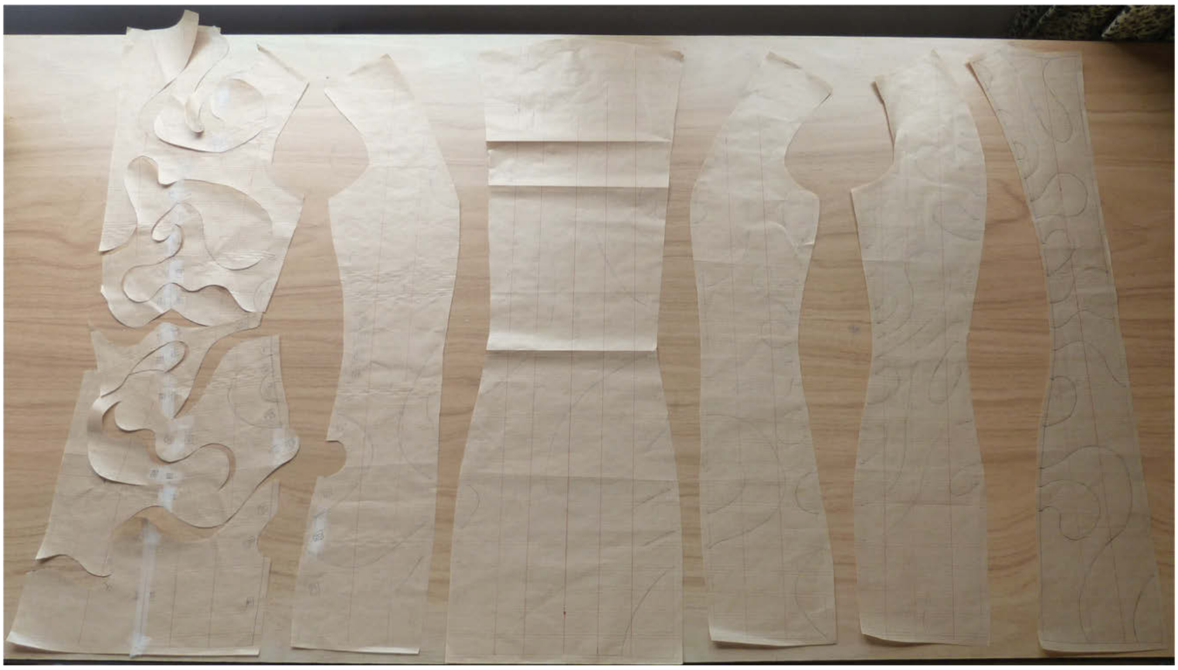
Model 4:

Pattern draped with straight edges.

Figure 3: The pattern with straight edges is almost indistinguishable from one with curved edges. Yet this pattern has fewer apex points, allowing more freedom to design style lines.

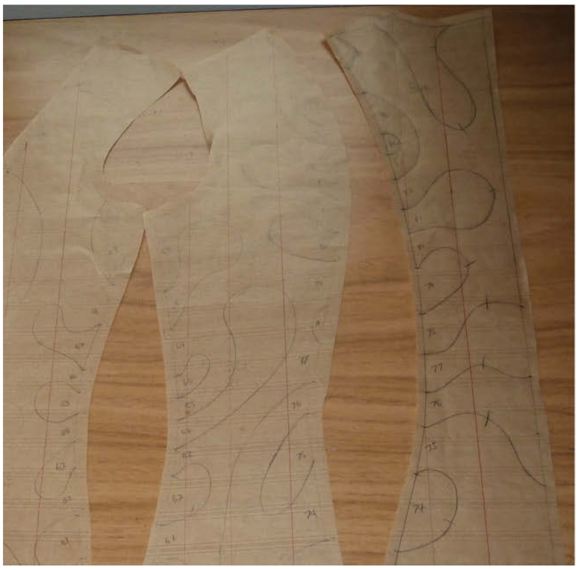
In the edges of one pattern it appears to be smooth curved lines, while the other consists of a series of straight lines. However, at this scale they are almost indistinguishable, and it is only possible to note the differences by examining the pattern in close detail.

Set 2:



Model 5

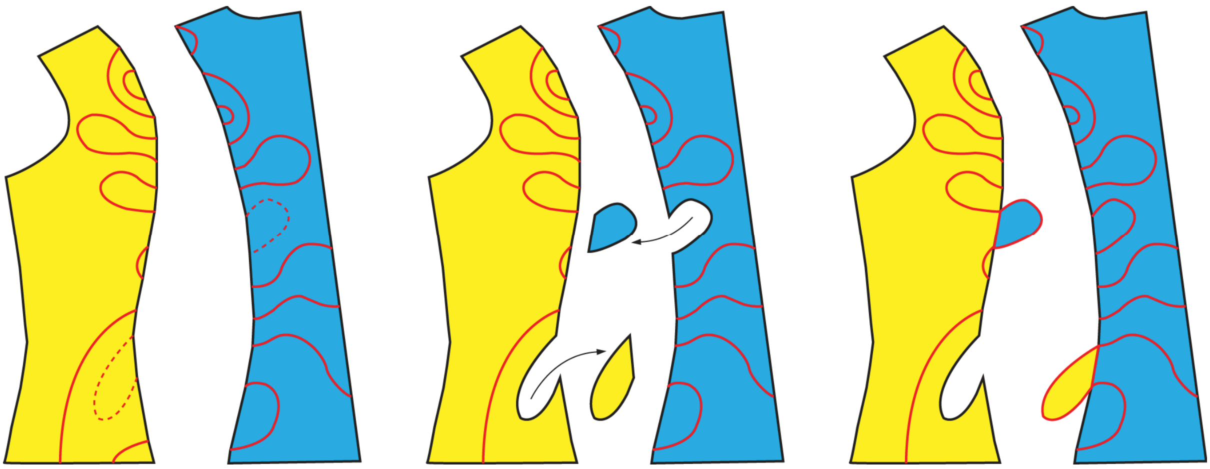
Figure 4: Complex design lines are drawn on the pattern. The design lines have to pass through each apex point.



Model 6

Model 7

Figure 5: The complexity of this pattern would usually result in a loss of accuracy. Yet, because all the contours are actually straight lines they can be manipulated without losing accuracy.



Model 8:
Curved design lines are cut out of a pattern to create a complex shape.

Model 9:
The curved design lines are cut out of a pattern and attached to their corresponding locations.

Model 10:
The patterns can easily be attached without loss of accuracy because the contoured sides of the patterns are straight edges, not curved lines.

Figure 6: When creating a complex pattern with curved lines there is no loss of accuracy because the contours of the patterns are actually straight lines and easily attach to the other patterns.

Set 3:

Model 11

Figure 7: This pattern is extremely complex, yet does not lose any geometric accuracy.

Model 12:

Pattern draped with curved edges.

Model 13:

New pattern draped on top of original pattern.

Figure 8: The front panel of the new pattern is draped on top of the front pattern of the original.

The new pattern fits precisely on top of the form of the original. The front panel of the new garment has an extremely complex series of designed lines, yet it maintains the fit of the original block pattern without losing geometric accuracy.

Conclusion

The experiment shows that it may deliberately drape a pattern with fewer apex points and still have an acceptable fit, allowing the patternmaker more freedom to create extremely intricate patterns without the loss of geometric accuracy. This is achieved as long as the style lines pass through the apex points. Hereby, the designer can create extremely complex patterns without losing the fit of the original garment.

10. Exotic Darts

Experiment 37: **"V" and heart darts**

Experiment 38: **Branching darts**

Aim

These two experiments explore darts with unconventional shapes that are able to intricately shape a garment. Darts with a "V" or heart shape have a unique structure that provides more sites for apex points. The experiments investigate darts with structures that branch out in shape to create more sites for apex points, offering the patternmaker more opportunities to alter the garment's shape.

Method

The first experiment examines "V" or heart-shaped darts and analyses their structure using contour manipulation. The second explores how structures with branches offer more sites for apex points. Using contour manipulation, it tests diverse structures that branch into different configurations.

Analysis

"V" or heart-shaped darts have a unique structure that creates a gusset in the centre of the dart. The seam line of a "V" dart branches in two, making a "Y" shape. When the seam line branches, it creates more sites for apex points. Structures with curved shapes such as the heart dart also generate more apex points. The second experiment also explores how a seam line that branches into multiple seam lines generates more sites for apex points. It tests different configurations of darts that maximise the amount of dart apexes. Building darts with branch-like structures offers new opportunities to create more apex points. Further, the shape of these structures can offer different configurations of darts and gussets.

Experiment 37: "V" and Heart Darts

Rationale

This experiment examines patternmaking structures that use many apex points to optimise their structure. When creating darts, patterns that have a "V" or heart shape tend to have more apex points than simple straight-edged darts. Through a series of iterations it explores the properties of different variations of "V" and heart-shaped darts. These darts are deconstructed into a series of darts and gussets in order to understand their structure and function.

Hypothesis

The research anticipates that the structure of a "V" or heart shape allows a pattern to have more apex points and a longer seam line than conventional straight-edged darts.

Experimental Design

Through a series of different paper models, variations of "V" and heart darts are examined. The first part of the experiment analyses the structure of "V" shaped darts and what offers them more sites for apex points. The second part explores heart-shaped darts that use a similar structure to "V" shaped darts. The curvature of the heart-shaped pattern also creates more sites for apex points. The third part explores some hypothetical patterns that allow even more apex locations.

Procedure

The experiment consists of three parts. They require a pattern to be drawn flat, followed by analysis of its three-dimensional structure.

Part 1: "V" shaped darts

Set 1:

Model 1: Create a "V" shaped dart.

Model 2: Analyse the structure of the "V" shaped dart. Identify all the apexes on the pattern.

Model 3: Simulate sewing the seam line of the "V" shaped dart to show the shape of the seam.

Observe the properties of these models.

Set 2: Asymmetrical “V” shaped dart

Model 4: Create an asymmetrical “V” shaped dart. The apex on the right side of the dart should be lower than the right side of the dart.

Model 5: Analyse the structure of the asymmetrical “V” shaped dart. Identify all the apexes on the pattern.

Model 6: Simulate sewing the seam line of the asymmetrical “V” shaped dart to show the shape of the seam.

Observe the properties of these models.

Part 2: Heart-shaped darts

Set 3:

In this pattern, one side of the “V” shaped dart and pattern starts to take on the form of a heart shaped dart.

Model 7: Create an asymmetrical “V” shaped dart with the right side of the dart as a curved line.

Model 8: Analyse the structure of the asymmetrical “V” shaped dart. Identify all the apexes on the pattern.

Model 9: Simulate sewing the seam line of the asymmetrical “V” shaped dart to show the shape of the seam.

Observe the properties of these models.

Set 4:

This pattern is a heart-shaped dart with curves.

Model 10: Create a heart-shaped dart.

Model 11: Analyse the structure of the heart-shaped dart. Identify all the apexes on the pattern.

Model 12: Simulate sewing the seam line of the heart dart to show the shape of the seam.

Observe the properties of these models.

Part 3: Examples of heart-shaped darts

Set 5:

This part of the experiment explores different hypothetical patterns for heart-shaped darts that can create different shapes.

Model 13: Create the pattern for an asymmetrical heart dart.

Model 14: Create the pattern for a concave symmetrical heart dart.

Model 15: Create the pattern for a convex symmetrical heart dart.

Model 16: Create the pattern for a symmetrical heart dart.

Model 17: Create the pattern for a stylised heart shaped dart.

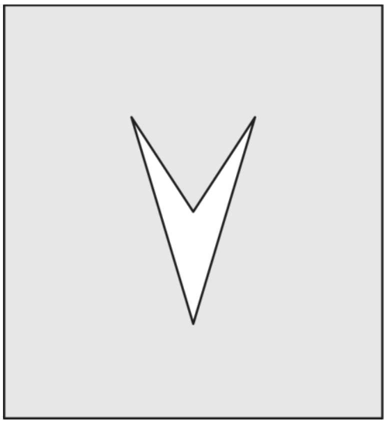
Model 18: Create the pattern for a heart-shaped dart with a shape embedded in the centre.

Observe the properties of these models.

Results

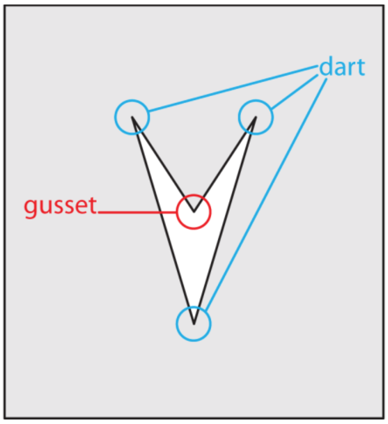
<u>Part 1</u>: “V” shaped darts

Set 1:



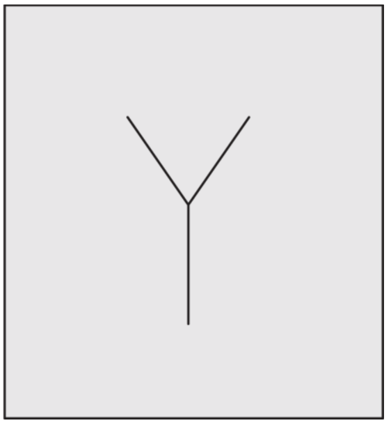
Model 1:

Structure of pattern.



Model 2:

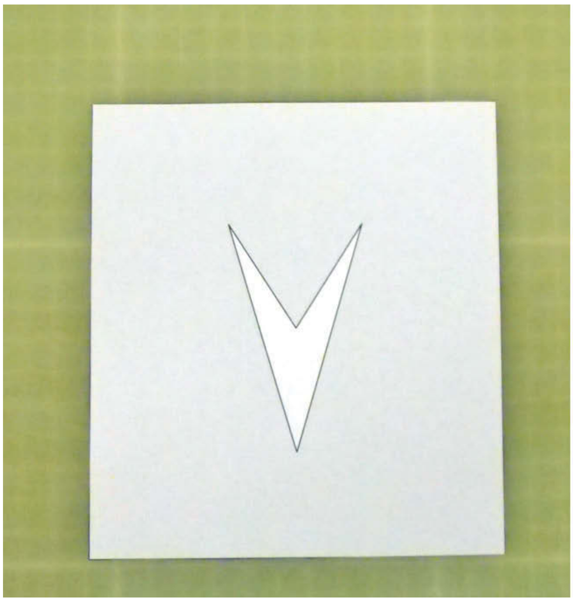
Function of pattern.



Model 3:

Shape of the seam line.

Figure 1: The “V” or heart dart creates three darts and a gusset.



Model 1:

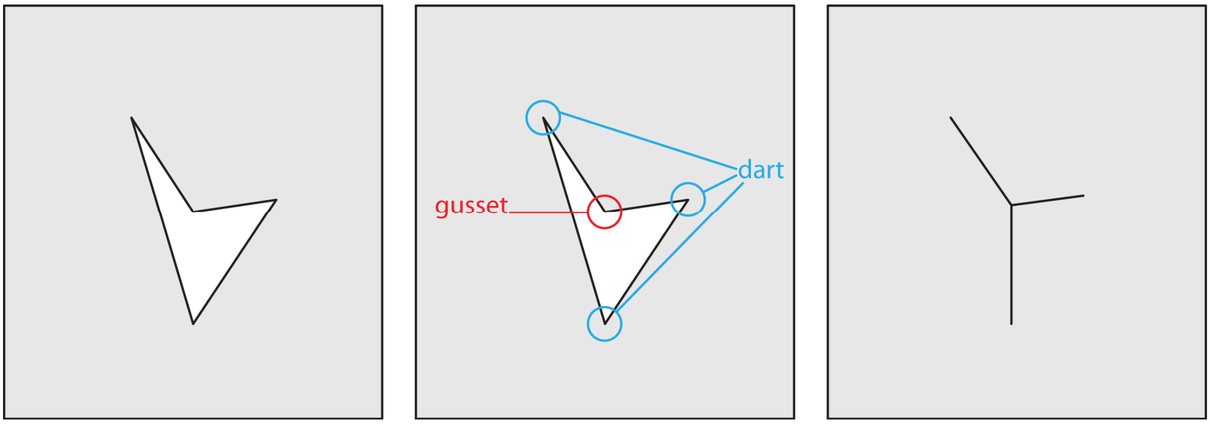
Structure of pattern.

Model 3:

Shape of the seam line.

Figure 2: Paper models of **Figure 1.**

Set 2:

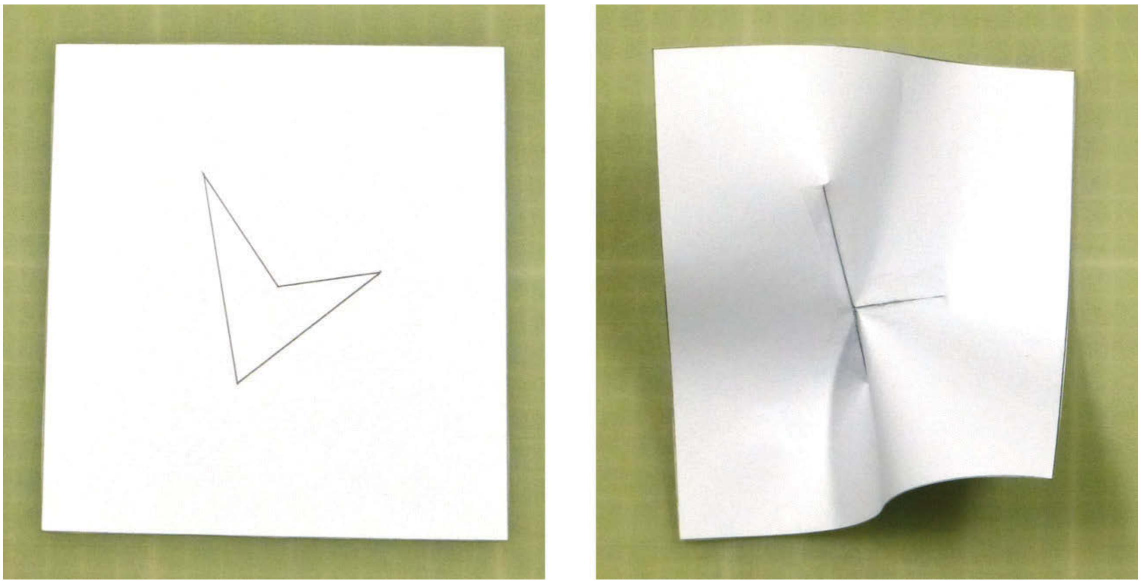


Model 4:
Structure of pattern.

Model 5:
Function of pattern.

Model 6:
Shape of the seam line.

Figure 3: "V" or heart darts can be asymmetrical.



Model 4:
Structure of pattern.

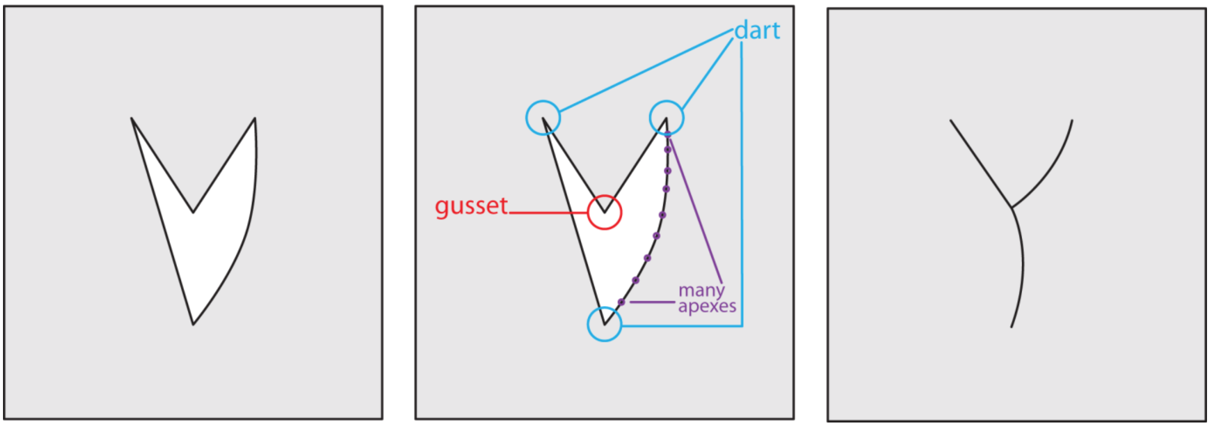
Model 6:
Shape of the seam line.

Figure 4: Paper models of **Figure 3.**

It is observed that the branching structure of the seam line (see models 3 and 6) created by the "V" shape seems to create more locations for apex points.

Part 2: Heart-shaped darts

Set 3:

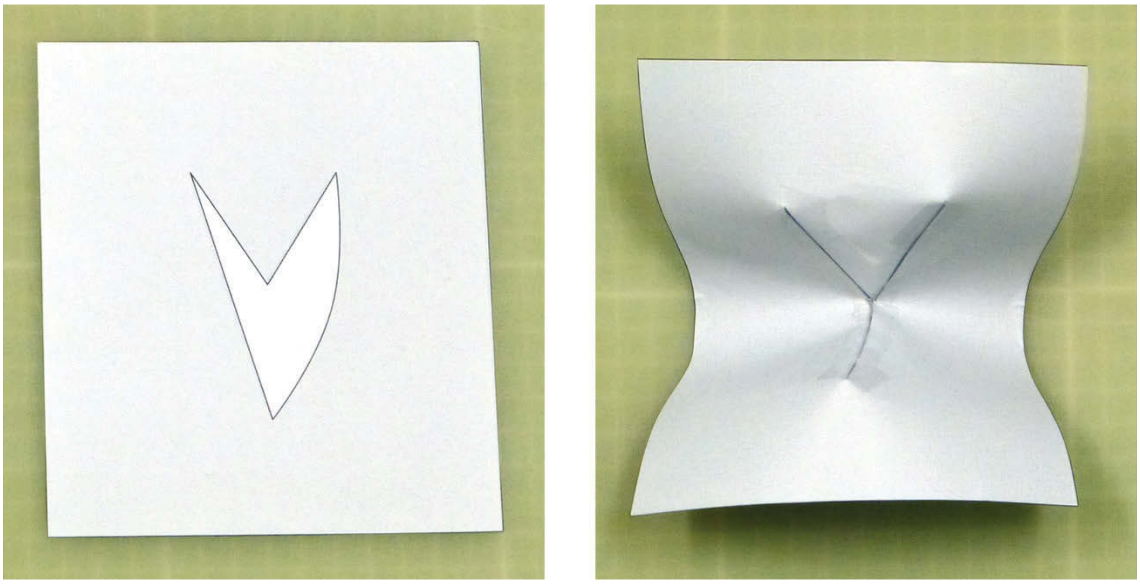


Model 7: Structure of pattern.

Model 8: Function of pattern.

Model 9: Shape of the seam line.

Figure 5: "V" or heart darts can be curved to create many apexes.



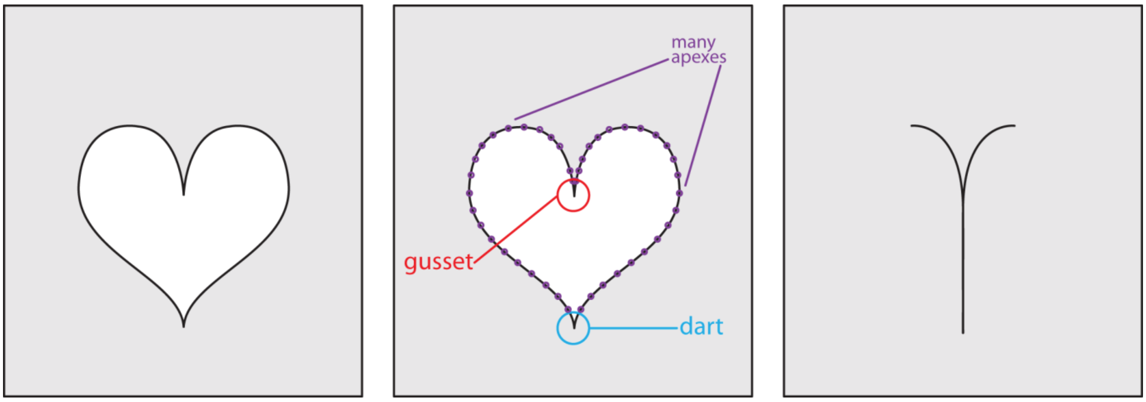
Model 7: Structure of pattern.

Model 9: Shape of the seam line.

Figure 6: Paper models of **Figure 5.**

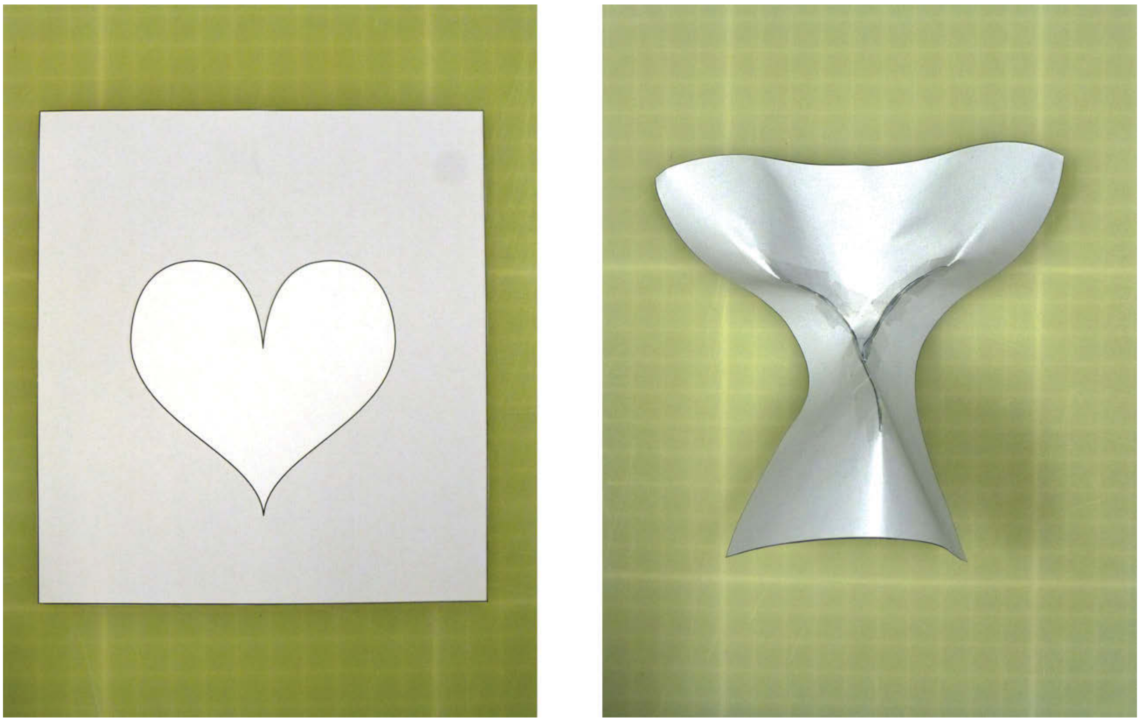
It is observed that the addition of curves to the "V" shaped structure creates more sites for apex points.

Set 4:



Model 10: Structure of pattern. | Model 11: Function of pattern. | Model 12: Shape of the seam line.

Figure 7: Curved versions of the "V" or heart dart create even more apexes.



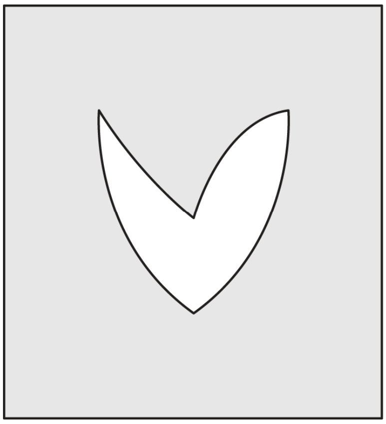
Model 10: Structure of pattern. | Model 12: Shape of the seam line.

Figure 8: Paper models of **Figure 7.**

It is observed that the curved shape of the heart shape create more sites for apex points.

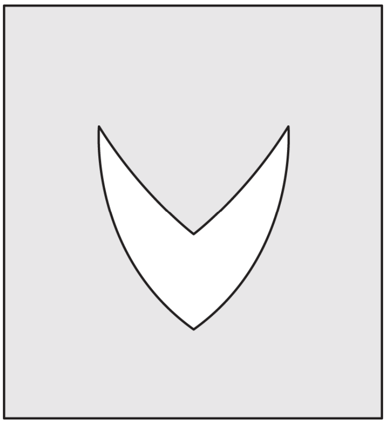
Part 3: Examples of heart-shaped darts

Set 5:



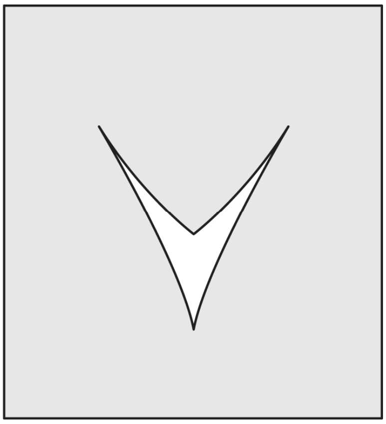
Model 13:

Asymmetrical heart dart.



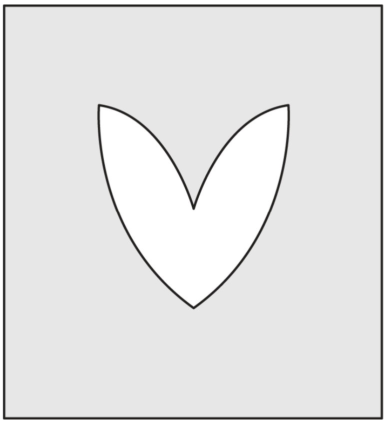
Model 14:

Concave symmetrical heart dart.



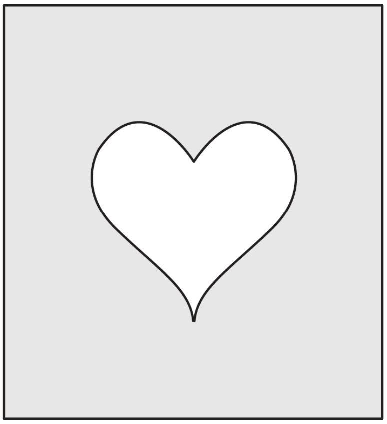
Model 15:

Convex symmetrical heart dart.



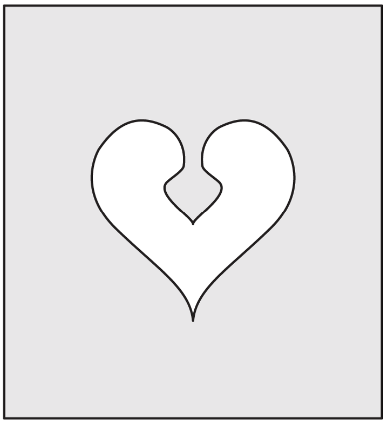
Model 16:

Symmetrical heart dart.



Model 17:

Heart-shaped heart dart.



Model 18:

Heart dart with embedded shape.

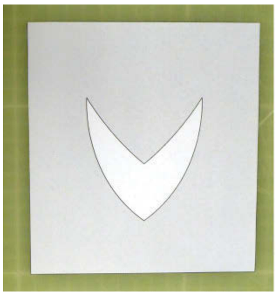
Figure 9: Examples of many different kinds of heart dart. Each shape creates a distinct three-dimensional shape.

Model 13:

Structure of pattern.

Model 13:

Shape of the seam line.

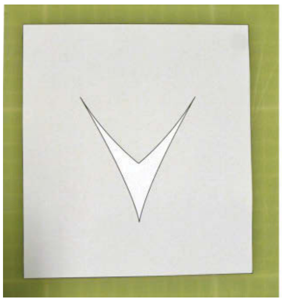


Model 14:

Structure of pattern.

Model 14:

Shape of the seam line.



Model 15:

Structure of pattern

Model 15:

Shape of the seam line

Model 16:

Structure of pattern

Model 16:

Shape of the seam line

Model 17:

Structure of pattern

Model 17:

Shape of the seam line

Model 18:

Structure of pattern

Model 18:

Shape of the seam line

Model 18:

Side view of dart.

Figure 10: Paper models of **Figure 9**.

These patterns can generate apex points and dramatically shape a pattern in a very small structure, offering a way to distil multiple darts or contours patterns into a single patternmaking structure that has many apexes.

Conclusion

The experiment shows that the branching structure of seam lines in a “V” shaped dart creates more sites for apexes, allowing the patterns to be shaped in greater detail. Heart-shaped darts also take advantage of this structure by making the seam line of the structure branch in two, utilising the curved shape of the pattern to create more apex points. Part 3 of the experiment offers examples of different patterns that use many apexes to curve the pattern shape. By understanding how to create structures that increase the number of apexes, patternmakers can create more sophisticated patterns.

Experiment 38: Branching Darts

Rationale

The aim of this experiment is to understand how darts with branching tree structures can be used to create more locations for apex points. In previous experiments "V" shaped or heart- shaped darts were able to create a large number of apex points in a small area. This experiment tests how larger branching darts structures create more sites for apex points, aiming overall to explore the properties of darts with branching structures.

Hypothesis

The research anticipates that as a dart creates more branches it will create more apex points.

Experimental Design

The experiment tests whether by creating darts with more branches it is possible to create more apex points. The first set of iterations compares darts with different numbers of branches. It begins with a diamond-shaped dart with a single seam line, and compares it to a "V" shaped dart which creates two branches when the pattern is sewn together. This in turn is compared with a pattern with an arrowhead shape and three branches when sewn together. It then compares these three patterns to see what darts and gussets their apexes create.

The second part of the experiment looks at different ways branch structures can grow to increase the number of apex locations. The first set starts with a "Y" shaped tree structure. The end of the "Y" shape becomes the centre point of the pattern. Additional branches are created by attaching more "Y" shapes to the end. The next set takes the top two branches of a pattern and divides them into two new branches. This process is repeated, increasing the number of branches. The final set creates an asymmetrical pattern. Starting with a "Y" shaped branch, more "Y" shapes are added to the side of the pattern. This process of adding a "Y" shaped branch to one side, creates the asymmetrical pattern.

Procedure

The experiment draws a pattern, then analyses its structure. The pattern's shape can also be simulated to show the shape of its seam line when the pattern is sewn together. The first part of the experiment examines how changing the pattern's structure can increase the number of sites for apex points. The second part explores hypothetical branching structures, as well as ways branching can be used to create apex points in different configurations.

Part 1: Branching structures

Set 1: Diamond-shaped dart

Model 1: Create a diamond-shaped dart.

Model 2: Analyse the structure of the diamond shaped dart. Identify all the apexes on the pattern.

Model 3: Simulate sewing the seam line of the diamond shaped dart to show the shape of the seam.

Observe the properties of these models.

Set 2: "V" shaped dart

Model 4: Create a "V" shaped dart.

Model 5: Analyse the structure of the "V" shaped dart. Identify all the apexes on the pattern.

Model 6: Simulate sewing the seam line of the "V" shaped dart to show the shape of the seam.

Observe the properties of these models.

Set 3: Trident-shaped dart

Model 7: Create a trident-shaped dart that has three distinct branches at the top.

Model 8: Analyse the structure of the trident-shaped dart. Identify all the apexes on the pattern.

Model 9: Simulate sewing the seam line of the trident-shaped dart to show the shape of the seam.

Observe the properties of these models.

Part 2: Tree structures

The second part of the experiment explores different tree-shaped structures and the different configurations that can place apex points in different locations. By taking a simple pattern and growing branches, different tree-shaped structures can be observed.

Set 4: Growing from a central point

Model 10: Create a pattern with a "Y" shaped branch structure.

Model 11: Create a pattern with a point in the middle of the pattern. From the central point place a "Y" shaped branch at the top and bottom of the pattern to make an "X" shape.

Model 12: Create a pattern with a point in middle of the pattern. From this central point, place three "Y" shaped branches that face in different directions.

Set 5: Growing from the top.

Model 13: Create a pattern with a "Y" shaped branch structure.

Model 14: Take the top two branches of the pattern and place "Y" shaped branches on top of them.

Model 15: Take the top four branches on the pattern and replace them with "Y" shaped branches.

Set 6: Growing an asymmetrical pattern

Model 16: Create a pattern with a "Y" shaped branch structure.

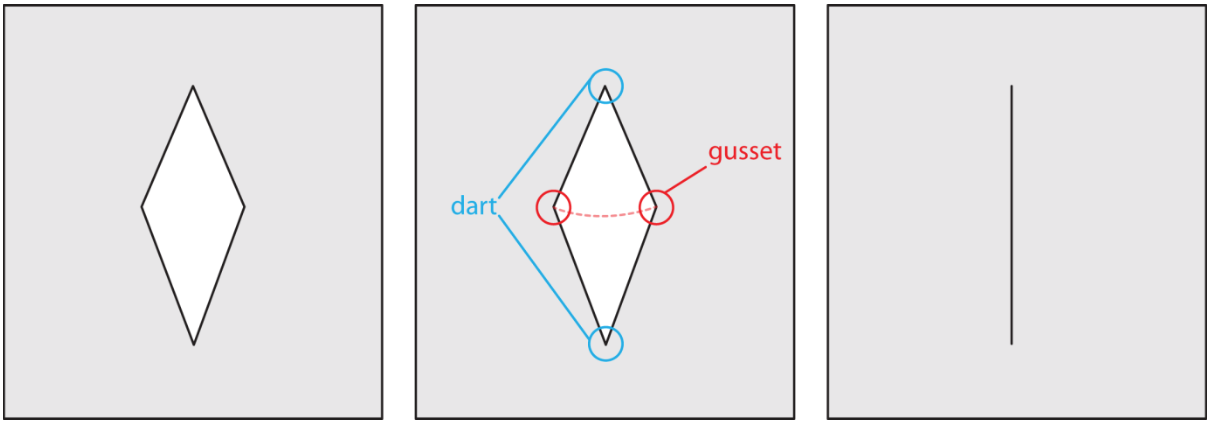
Model 17: Add an addition "Y" shaped branch to the right side of the pattern.

Model 18: Add an additional "Y" shaped branch to the branch on the furthest right of the pattern.

Results

Part 1: Branching structures

Set 1: Diamond-shaped dart



Model 1: Structure of pattern.

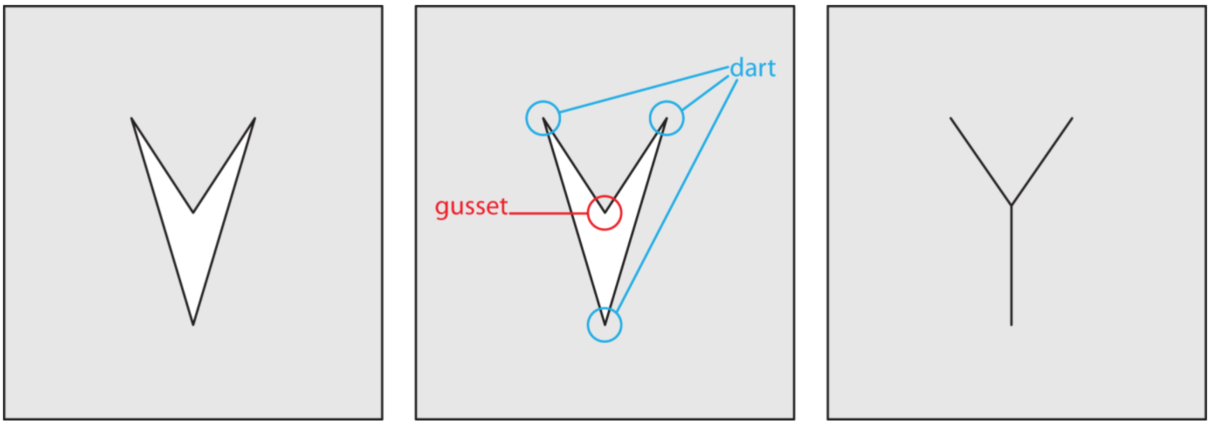
Model 2: Function of pattern.

Model 3: Shape of the seam line.

Figure 1: A single seam line has a limited amount of locations for apexes.

It is observed that this pattern only has a single seam line.

Set 2: "V" shaped dart



Model 4: Structure of pattern.

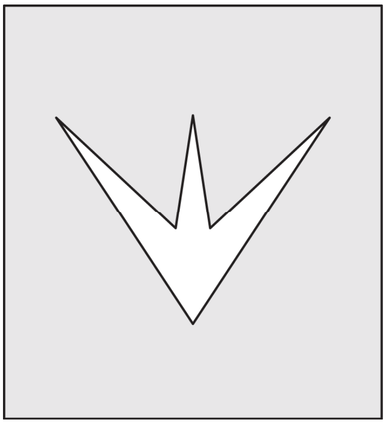
Model 5: Function of pattern.

Model 6: Shape of the seam line.

Figure 2: A branching structure has more sites for apexes.

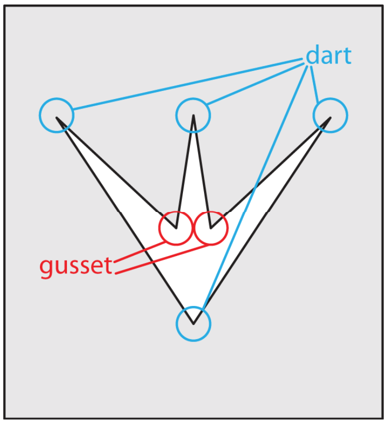
It is observed that this pattern only has a branching "Y" shaped structure.

Set 3: Trident-shaped dart



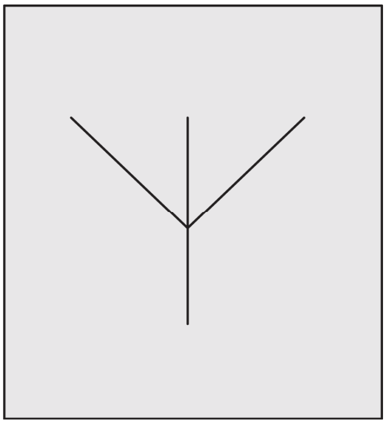
Model 7:

Structure of pattern.



Model 8:

Function of pattern.



Model 9:

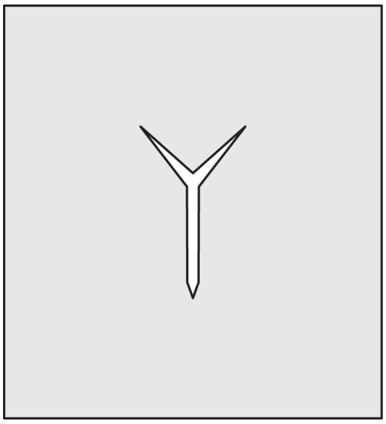
Shape of the seam line.

Figure 3: A branching tree structure has even more sites for apex locations.

It is observed that this pattern only has a branching-shaped structure with three branches on the top. The more branches a pattern has, the more locations it offers to form apex points.

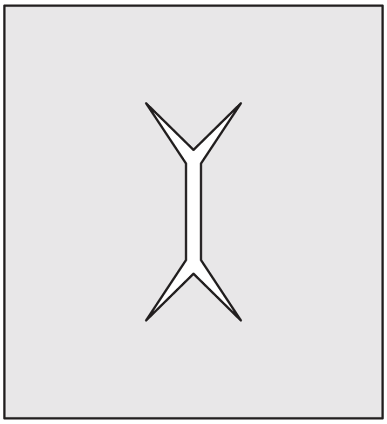
Part 2: Tree structures

Set 4: Growing from a central point



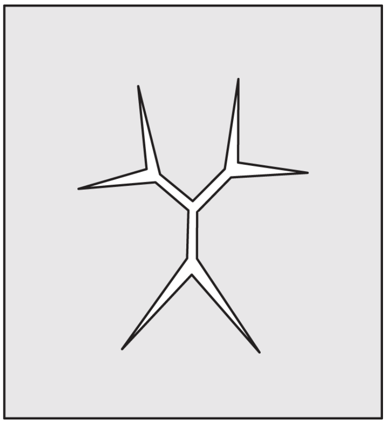
Model 10:

A "Y" shaped branch.



Model 11:

An "X" shaped branch.



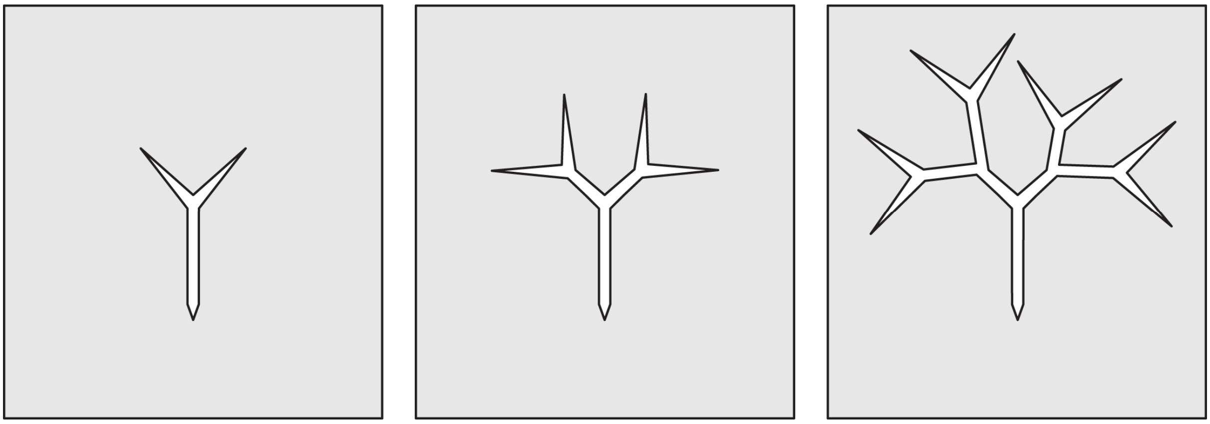
Model 12:

A "Y" shaped branch mounted on the end of a "Y" shaped branch.

Figure 4: Branching structures create more locations for apex points to shape the garment.

Growing branches from a central point is an effective way of evenly packing a large number of apex points in a small area.

Set 5: Growing from the top



Model 13:
A branch structure.

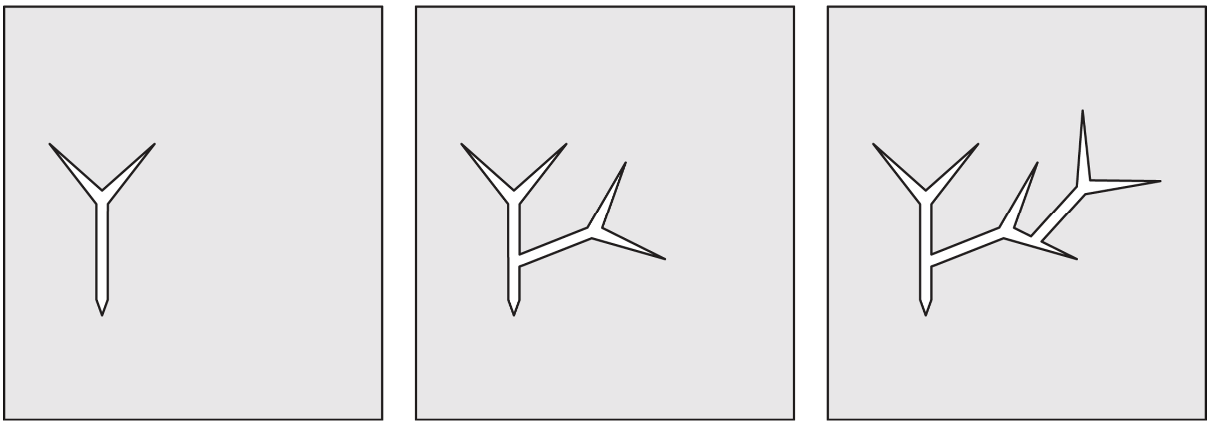
Model 14:
The branches of the structure create their own branches.

Model 15:
The branches of the structure create even more branches.

Figure 5: The more branch structures that are created the more sites for apexes.

Growing branches on only the top of the pattern is an effective way of densely packing a large amount of apex points in a small area.

Set 6: Growing an asymmetrical pattern



Model 16:
A branch structure.

Model 17:
An additional branch creates an asymmetrical structure.

Model 18:
An additional branch creates even more complex asymmetrical structures.

Figure 6: Creating asymmetrical structures using branches is an effective way to create more sites for apexes.

Growing branches on only one side is an effective way of creating an asymmetrical pattern.

Conclusion

The experiment demonstrates that by creating patterns with branching structures, it develops more locations for placing dart apex points. This offers patternmakers opportunities to create the effect of multiple structures in sophisticated branching formations.

11. Reshaping Darts and Contours

Experiment 39: **Re-shaping contours and moving dart apexes**

Experiment 40: **Creating elliptical cross-sections to move apex points**

Aim

These experiments address the need for a technique that can move the location of the dart apex points around the pattern while maintaining a similar fit to the original garment. Patternmakers need such a technique for functional and aesthetic purposes. Here, the research offers them greater creative freedom. Conventional techniques that move the location of the dart apex change the surface area and cone angle of the pattern, whereas the alternative technique treats the dart as a cone. Such a cone can be cut at different cross-sections and the tip rotated to create a pattern with a different shape but retaining the volume and surface area.

Method

This pair of experiments demonstrates a technique where a cone can be cut at an angle with an elliptical cross-section. The tip of the cone can be rotated 180° and re-attached to the base of the garment. This creates a pattern with the same surface area and volume as the original. The second experiment of the pair explores ways patternmakers can draft elliptical cross-sections onto cones. Further, it tests techniques involving computer software whereby it physically drafts patterns that allow different elliptical cross-sections to be generated.

Analysis

The ability to manipulate the shape of cones is a novel way to move dart apexes around the garment. A wide variety of techniques is available for generating elliptical cross-sections. Those that use computer software and mathematical calculations are effective but can be time-consuming. They are also not as hands-on as the physical techniques. One of the more successful uses plastic templates of ellipses to draw cross-sections on a 3D pattern. This lets the patternmaker precisely control the placement of the pattern.

Experiment 39: Reshaping Contours and Moving Dart Apexes

Rationale

This experiment offers a technique that allows a patternmaker to move the location of a dart apex while keeping the original surface area and volume of the garment. This is achieved by treating the dart as a cone and cutting the cone at an angle. This requires the cone to be cut by a flat plane and this creates a cross-section with an elliptical shape. Once the tip of a cone is cut off it can be rotated 180° and re-attached to the base of the pattern. This technique is a way of moving a dart apex without changing the surface area or cone height of a pattern.

Hypothesis

The research anticipates that cutting a cone at an angle will create an elliptical cross-section.

Experimental Design

The experiment demonstrates a technique whereby the tip of a cone can be cut at an angle that gives it an elliptical cross-section. The tip of the cone is then rotated 180° and attached to the base of the original garment. The first iteration shows the process on a cone, using a series of diagrams. The second section demonstrates how this process can be applied to the front of a garment pattern.

Procedure

Part 1: A cone

Model 1: Start with a cone pattern.

Model 2: The cone will be cut at an angle. Mark this line on the cone as an elliptical cross-section.

Model 3: Cut the pattern at an angle creating an elliptical cross-section.

Model 4: Rotate the tip of the cone 180°.

Model 5: Re-attach the tip of the cone to the base.

Make observations about how this affects the volume and surface area of the cone.

Part 2: A garment block

Model 6: Start with the front of a block garment pattern with a dart.

Model 7: The pattern will be cut at an angle. Mark this line as an elliptical cross-section.

Model 8: Cut the pattern at an angle creating an elliptical cross-section.

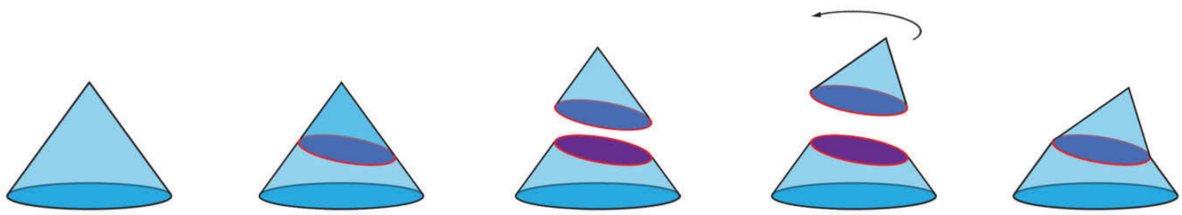
Model 9: Rotate the tip of the cone 180°.

Model 10: Re-attach the tip of the cone to the base.

Make observations about how this affects the volume and surface area of the cone.

Results

Part 1: A cone



Model 1: Start with a cone. | Model 2: Trace the cross-section of the cone. | Model 3: Cut off the tip of the cone. | Model 4: Rotate the tip of the cone. | Model 5: Re-attach the tip of the cone.

Figure 1: A technique to move the apex point of the cone by cutting off its tip at an angled cross-section and rotating it.

Part 2: A garment block

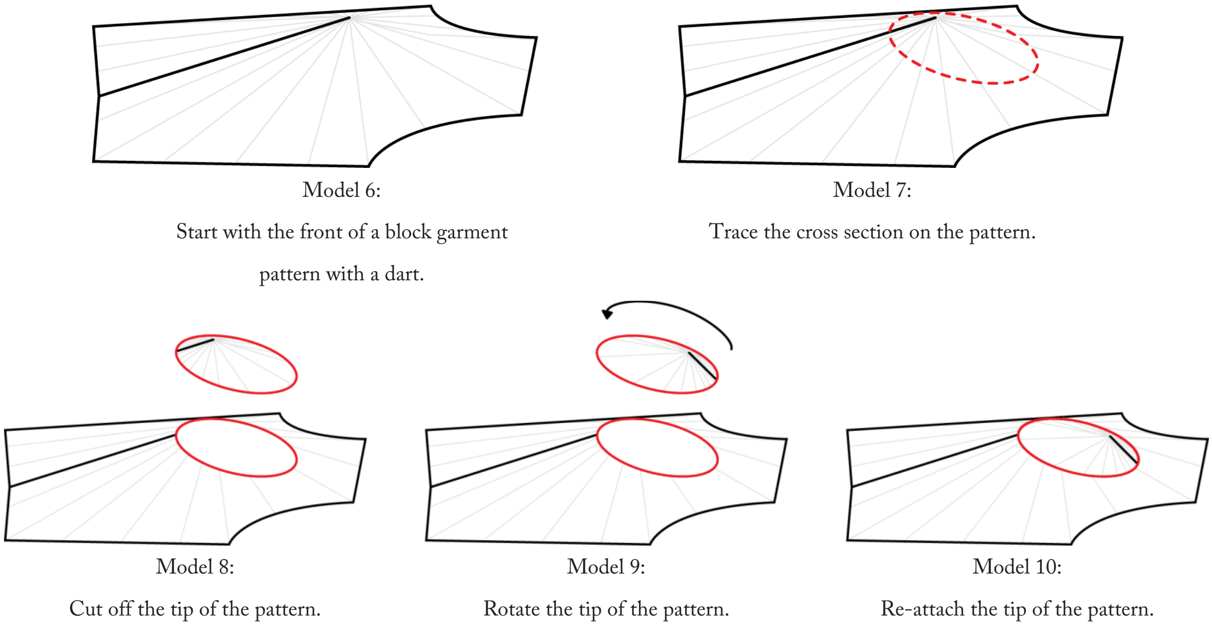


Figure 2: A technique for moving the apex point of the front of a block pattern piece, by cutting off the tip of the cone at an angled cross-section and rotating it.

Observations

In the experiment's first part, the cone is cut apart and re-arranged but volume and surface area remain the same. The same applies for the second part.

Conclusion

The experiment offers a technique for moving the location of an apex point while maintaining the garment's surface area and volume. This is a novel way of moving the location of apexes that can be applied anywhere a dart at an apex point can be found.

Experiment 40: Creating Elliptical Cross-Sections to Move Apex Points

Rationale

This experiment explores techniques for drafting ellipse-shaped cross-sections on cones. Cones can be cut at different angles, creating cross-sections of different shapes (see figure 1). The patternmaker, in order to move the location of an apex, must be able to cut a cone at different angles. Drafting elliptical shaped cross-sections on cones is sometimes an inaccurate process. The experiments test approaches and compare their effectiveness.

Hypothesis

The research anticipates multiple ways of drawing ellipse-shaped cross-sections, and that some techniques should be easier than others to implement.

Experimental Design

There are many approaches to drawing an elliptical cross-section for a cone. The research seeks a technique that is fast, accurate, reliable and easy for patternmakers to assimilate.

The first part of the experiment uses mathematical software on a website called Shodor (1994) to calculate the shape of an ellipse. This technique seems accurate, yet requires a computer and a printer, and is less hands-on than other techniques that are drafted directly onto paper patterns.

The second part of the experiment tests physical techniques for drafting elliptical cross-sections. It drafts cross-sections by immersing a cone in a container of water. Another approach uses a pen mounted on a stand to draw a cone of a uniform height.

The third part tests a combination of physical and mathematical techniques. One approach measures the length and width of an ellipse, then calculates its cross-section. Another approach uses plastic templates of elliptical shapes to draft ellipse shapes on a cone.

Following this, the research compares the effectiveness of the different techniques.

Procedure

This experiment has three parts.

Part 1: Computer techniques

Set 1: Shodor cross-section program

This experiment uses software on the Shodor website (Shodor 1994): http://shodor.org/interactivate/activities/CrossSectionFlyer/

Model 1: Use the program to create a cone, then draw an elliptical cross-section on the cone. Print out this new cone shape.

Part 2: Physical techniques

The second iteration tests a wide range of techniques that can be applied to a paper pattern to create a desired elliptical cross-section. These are inspired by Mnatsakanian's visual calculus techniques which often distil complex mathematical equations into simple physical processes (2012, p.172).

Set 2: Water

Model 2: Create an apparatus that can hold a paper cone at a standard height. This would resemble a large retort stand, capable of holding a cone. Take a glass beaker and place it under the cone holder. Place the paper cone at the desired angle in the cone holder. Use tape to hold the cone in place, if this helps. Fill the container with water so that the level of the water touches the edge of the cone, to create the desired elliptical cross section. The water should leave a mark on the pattern, showing the edge of the ellipse.

Set 3: A level pen

Model 3: Use the apparatus from the last experiment to hold a cone at a level height. Use tape to hold the cone in place. Use a retort stand to hold a felt-tipped pen with a fine nib at a level height. Make sure the apparatus is set up on a smooth and level surface. Position the paper cone at the desired height, then slide the pen so that it draws a level line on the cone. Slide the pen around the cone until an elliptical cross-section is achieved.

Part 3: Mathematical and physical techniques

The third part of the experiment relies on techniques that can be physically measured on a paper pattern but also require some mathematical calculation.

Set 4: Calculating a cross-section

This experiment relies on the idea that if the length and width of an ellipse is measured, it is possible to draft the curve of the cross-section. The pattermaker measures the cross section, then using a set of drafting procedures illustrated in figure 5, drafts the correct ellipse curve.

Model 4: Measure the length of the cross section.

Model 5: Measure the width of the cross section.

Model 6: With these measurements, it is possible to draft the ellipse of this cross-section.

Use the measurements and follow the drafting procedure in figure 6. This will deliver the right size of elliptical cross-section.

Set 5: Using plastic templates

The process of calculating and drafting an ellipse can be time-consuming and tedious. One alternative is to take plastic templates that already have on them pre-drawn ellipses of different sizes. The patternmaker can find the size of ellipse they like, then place it on a paper pattern to trace off an elliptical cross-section.

Model 7: Choose the size of ellipse to draw on a plastic template of ellipses.

Model 8: Place the plastic template on the cone and trace the cross-section of the cone. It may be easier to draw on the cone if a soft sponge or ball of stretch fabric is placed on the inside of the cone.

Model 9: Cut down the new elliptical line on the cone.

Model 10: Remove the tip of the cone.

Model 11: Rotate the tip of the cone 180°.

Model 12: Re-attached to the cone tip to the frustum.

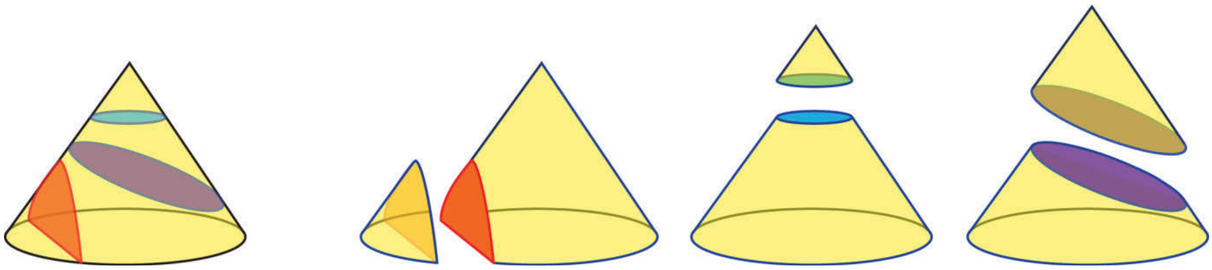
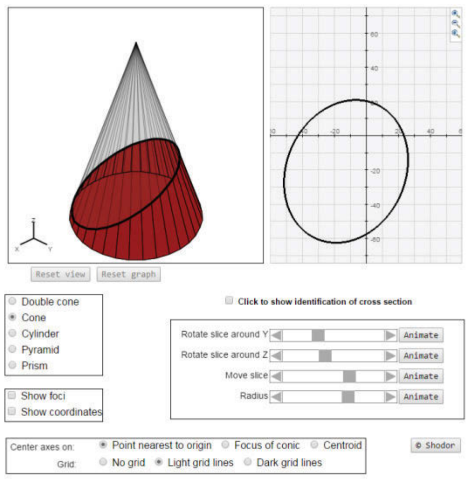


Figure 1: Cross-sections of many different shapes can be cut out of a cone.

Results

Part 1: Computer techniques

Set 1: Shodor cross-section program



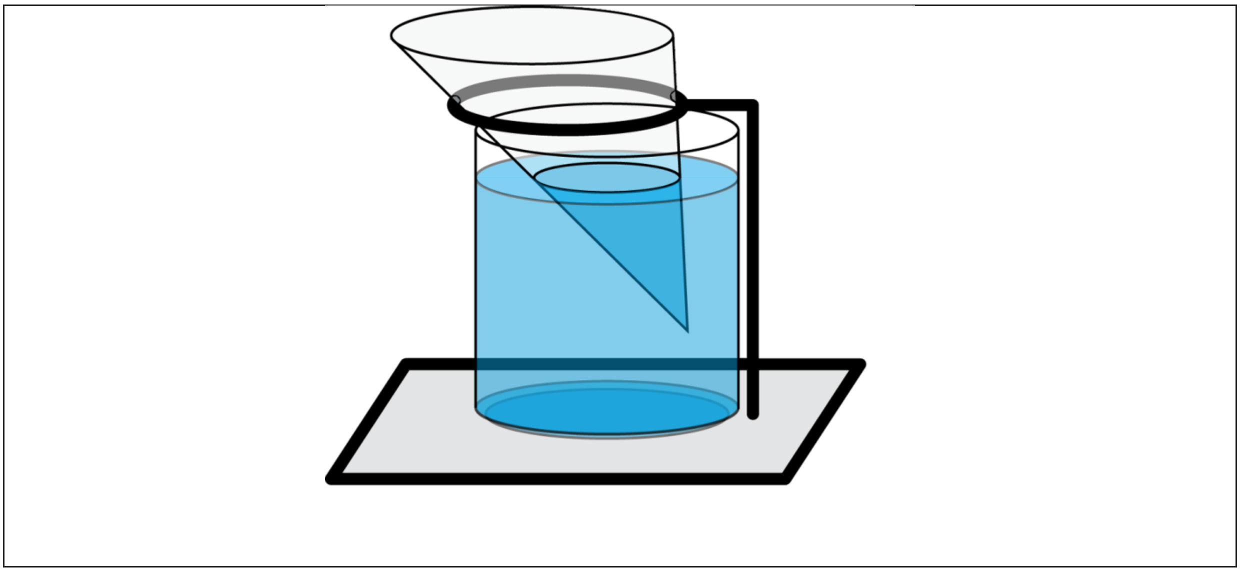
Model 1

Figure 2: The Shodor website has an application that can create different-shaped cross-sections on a cone (Shodor 1994).

Observations: Set 1

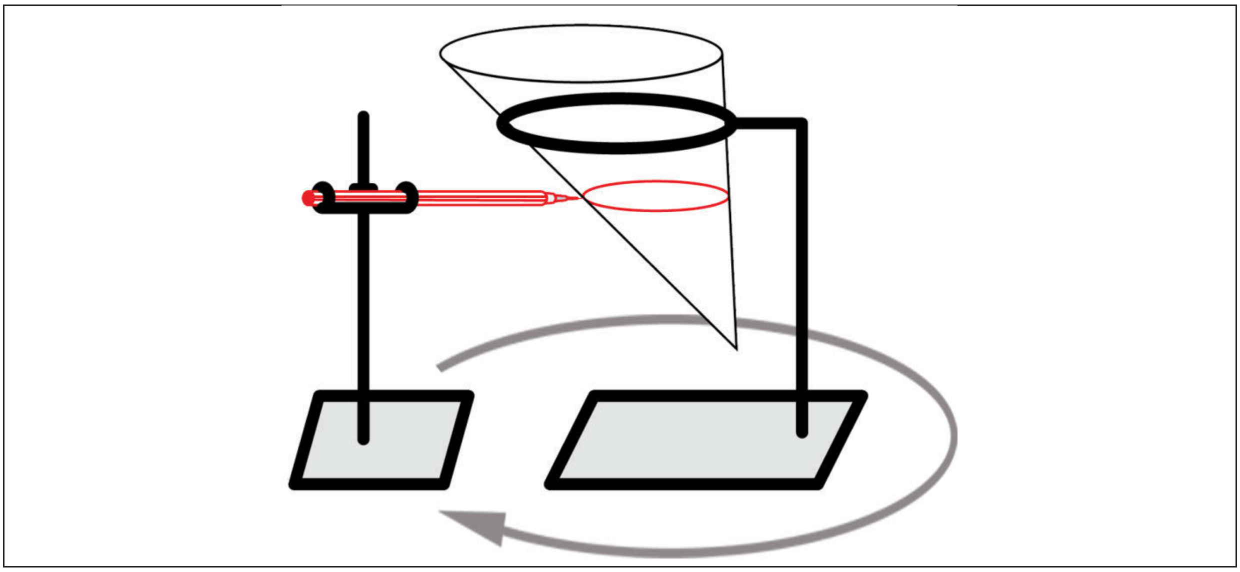
The computer program proves to be fast and effective, offering the patternmaker great control and visualisation of the entire process. The program visualises a cone whereby the cross-section can be moved around it. The cone size can be changed in height, radius and cone angle, while the cross-section can be tilted. The program is even capable of creating parabolic cross-sections. While the program is easy to use, the approach is less hands-on in that it does not let the patternmaker touch the physical cone.

Part 2: Physical techniques



Model 2

Figure 3: Set 2: An apparatus to dip a cone in a coloured cross-section so that its cross-section can be measured.



Model 3

Figure 4: An apparatus where a pen is set at a level height so that a cross-section can be traced from a cone.

Observations: Set 2

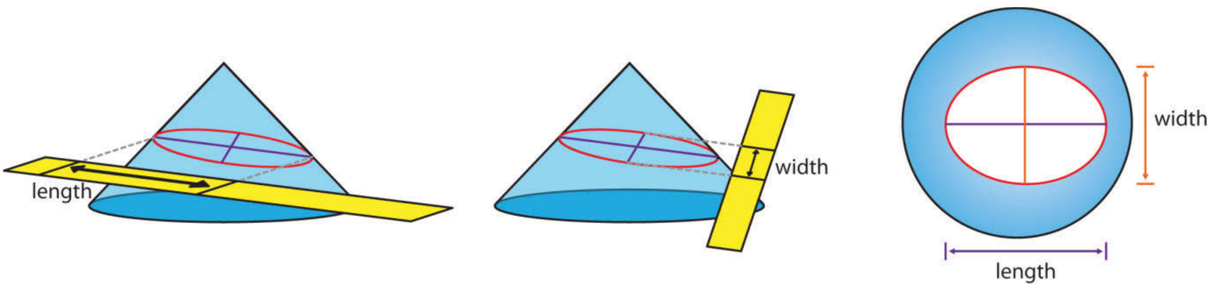
This experiment is not terribly effective. The water destroys the integrity of the paper, making the patterns hard to use. The water is messy and hard to control; it does not create clean lines, and makes it difficult to draw a smooth curve on the pattern.

Observations: Set 3

This iteration is very effective. As long as the patternmaker has a steady hand he may draw a smooth curved line on the pattern. Padding the cone with a sponge or filling it with fabric gives the pattern some resistance, making it even easier to draw the cross-section.

Part 3: Mathematical and physical techniques

Set 4: Measuring a cross-section



Model 4:
Take the length measurement.

Model 5:
Take the width measurement.

Model 6:
These measurements make it possible to draft the shape of the ellipse.

Figure 5: It is possible to draw any ellipse using its length and width measurement.

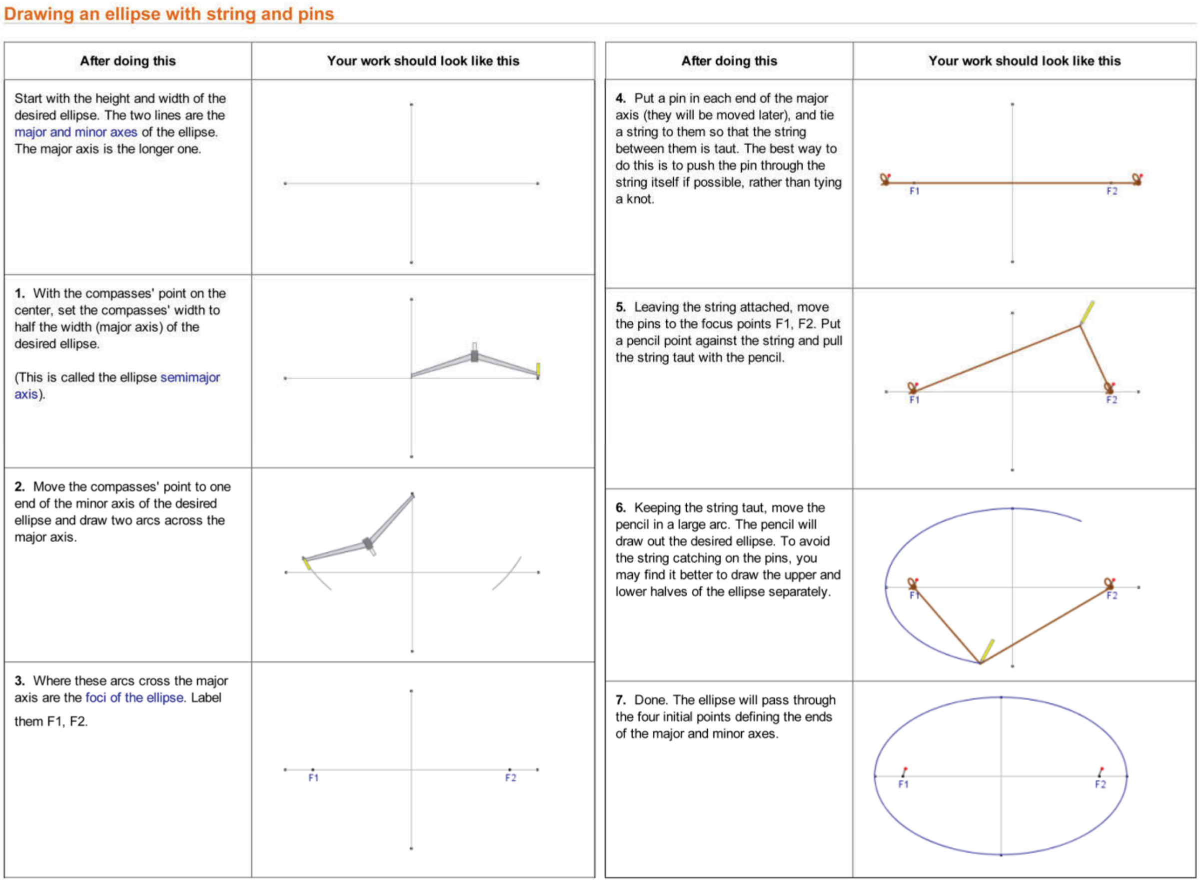
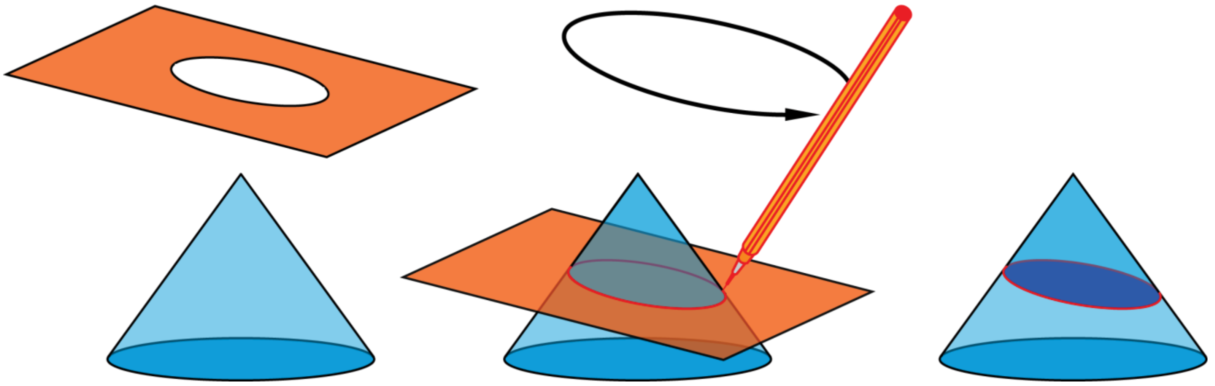


Figure 6: It is possible to draft the shape of an ellipse just by knowing its length and width measurements (Math Open Reference 2009).

<u>Observations</u>: Set 4

This experiment is effective yet time-consuming. It takes a very short time to measure the length and width of the fabric, but a long time to draft the ellipse. The other problem with this technique is that after all the drafting, the ellipse is still not drawn on the cone, as a template must still be translated onto the pattern.

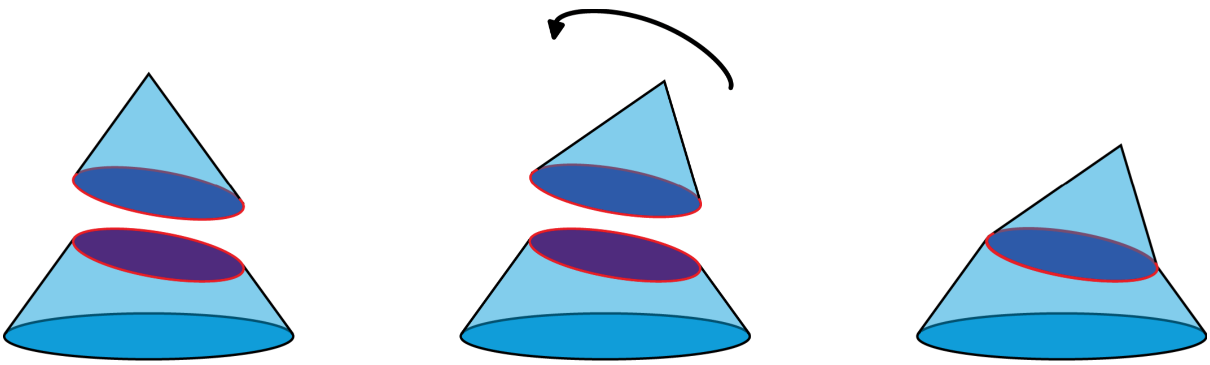
Set 5: Using plastic templates



Model 7: Start with a cone and an ellipse-shaped plastic template.

Model 8: Choose the cross-section and trace a line on the cone.

Model 9: Cut around the elliptical cross-section.



Model 10: Remove the tip of the cone.

Model 11: Rotate the tip of the cone.

Model 12: Re-attach the tip of the cone to the frustum.

Figure 7: An ellipse-shaped cross-section can be traced off a cone, cut off the pattern and re-attached to create a new shape. The new pattern will have a different three-dimensional shape, but the same surface area and volume.

<u>Observations</u>: Set 5

This technique is one of the most effective. It is fast, and the patternmaker can draft the exact shape they want on the pattern. Using the plastic ellipse templates is convenient. However, if the patternmaker is looking for a shape that is not on a plastic template, they can always use the technique in set 5 to draft a custom template.

Conclusion

The experiment reveals there are many techniques for finding a cone's elliptical cross-section. Computer software such as that on the Shodor website (1994) is an effective means of calculating very precise shapes. However, viewing images on a screen and printing them out slows the process. Physical, tactile techniques are very useful, as are techniques that mounted a pencil on a stand to trace around the cone. By contrast, dipping a cone into water is messy and ineffective. Measuring the length and width of the cone and then calculating the cross-section is effective, although time-consuming. Finally, the technique of using plastic templates to mark out the elliptical cross-sections is one of the most effective.

12. Wrinkle Analysis

Experiment 41: **Wrinkle analysis, part 1**

Experiment 42: **Wrinkle analysis, part 2**

Aim

These two experiments analyse the shape of wrinkles in order to understand their structure and function. Although wrinkles are traditionally seen as a defect in the fit of a garment, they do help to show how it can be altered to fit the shape of the body. The research applies contour manipulation to wrinkles, these “temporary” structures can be analysed with the precision of a static pattern, whereby it can quickly analyse the pattern’s shape at any point in time. Wrinkle patterns can become incredibly complex in shape; however, it can deconstruct complex wrinkle structures into a series of simpler shapes that are easier to analyse.

Method

The first experiment aims to analyse wrinkles with the same precision as patternmaking structures, showing how wrinkles form temporary structures closely akin to darts. Such wrinkles can be analysed using contour manipulation to make a pattern of the body-shape the garment lies on. The second experiment examines common wrinkle structures that occur in patterns. Being able to identify these lets the patternmaker quickly deconstruct a complex wrinkle into a series of simpler structures. This shows how the surface of a pattern without wrinkles creates a flat pattern that can be used to map the underlying body shape.

Analysis

In effect, the experiments analyse wrinkles as distinct patternmaking structures that can be mapped to gain useful insight into the body’s shape. Traditionally, wrinkle “analysis” has been more of a guide or rule-of-thumb measurement. That wrinkles are temporary structures should never limit the patternmaker's ability to identify their structure and function. A temporary wrinkle structure is similar to a configuration that is sewn into a static pattern. Such wrinkles can even be identified as common shapes, namely "X", "Y", "Z", "S", zig-zag and crescent-shaped. These tags allow complex wrinkle patterns to be deconstructed into a series of simpler structures, giving the techniques needed for quickly and precisely mapping the human body shape in different positions.

Experiment 41: Wrinkle Analysis, Part 1

Rationale

This experiment analyses wrinkles as complex patternmaking structures that can be objectively measured and recorded. Fabric models are draped on a mannequin in a position that creates wrinkles. These are then analysed as geometric structures. In fashion patternmaking, wrinkles are often seen as imperfections in a properly-fitted garment. While wrinkles are not considered to have their own structure and function, when the body moves many wrinkles are created. Wrinkle analysis is often used as a way to make rough observations on the fit of clothing based on the wrinkles created. However, by analysing wrinkles as unique geometric structures, the patternmaker can better understand their function.

Hypothesis

The research anticipates that wrinkles are complex structures that can, with enough time and effort, be mapped. Using contour manipulation it seeks to deconstruct any wrinkle structure into a detailed flat pattern. Wrinkles from a geometric perspective have a slightly different structure to flat patterns. The latter have intrinsic curvature while wrinkles display extrinsic curvature (see figure 1). This means that they deform the surface of the pattern without changing the underlying structure of the pattern.

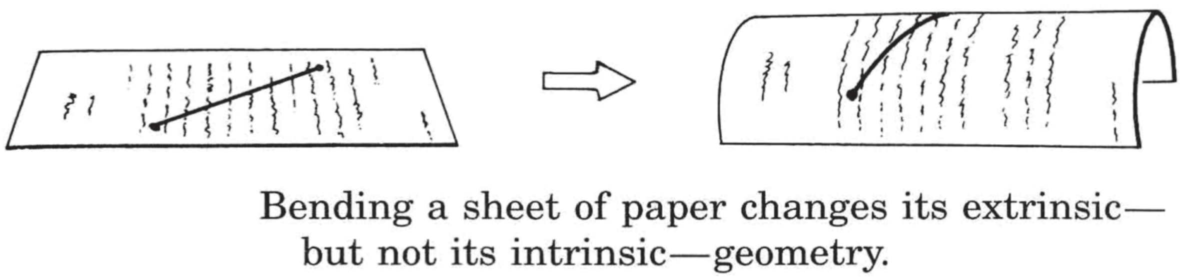


Figure 1: Bending a surface creates "extrinsic curvature" (Weeks 2002, p. 35).

Experimental Design

This experiment explores, in four parts, the many properties of wrinkles as patternmaking structures.

The first part compares pieces of fabric placed on a curved Euclidean surface to a pattern placed on a hyperbolic-shaped surface. The fabric on the hyperbolic-shaped surface will wrinkle. It proceeds to analyse their shapes, as well as the pattern shapes that make contact with the hyperbolic surface.

The second part analyses different structures that commonly occur in wrinkles, including temporary-form structures that behave similarly to structures that are sewn in place.

Procedure

Set 1:

Model 1: Take a curved Euclidean surface and drape a rectangular piece of fabric on the surface. Observe to see if there are wrinkles created.

Model 2: Take a curved hyperbolic surface and drape a rectangular piece of fabric on the surface. Observe to see if there are wrinkles created. If so, analyse their structure in three dimensions. Observe the parts of the fabric that make contact with the curved surface and generate a diagram to show the pattern created by the wrinkles.

Set 2:

This experiment compares a wrinkle that has the structure of a dart, with a dart that is sewn in place.

Model 3: Take a rectangular piece of fabric and pinch out a dart. Sew the dart in place.

Model 4: Take a rectangular piece of fabric pinch out a dart of the exact size, but leave it as a wrinkle instead of sewing it in place.

Model 5: Take a rectangular piece of fabric pinch out a dart of the exact size, this time folding the wrinkle in the opposite direction. Leave the pattern as a wrinkle instead of sewing it in place.

Compare the properties of the pattern that has wrinkles, to the structure of the pattern sewn in place line darts.

Set 3:

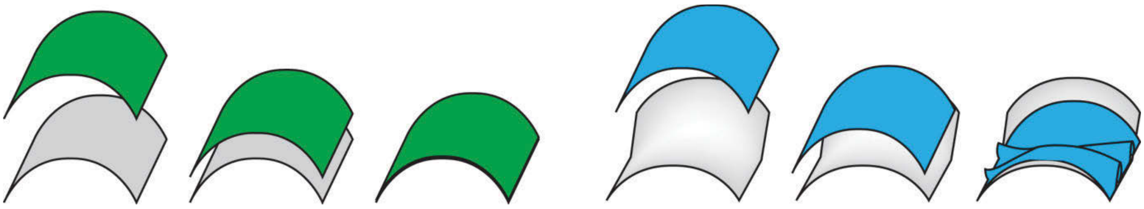
The third iteration takes the wrinkle pattern from set 1 and analyses it as a series of darts and contours.

Model 6: Take the wrinkle pattern from model 2.

Model 7: Pinch out all the wrinkles to turn them into a series of darts and contours. Sew or pin these wrinkles in place and analyse their structure.

Results

Set 1:



Model 1:
No wrinkles.

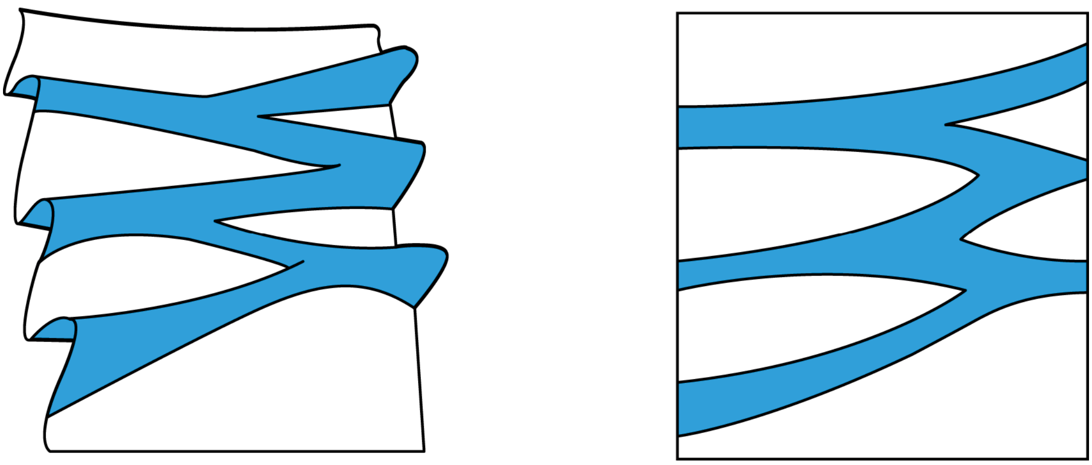
Model 2:
Wrinkles.

Figure 2: Wrinkles are created when the pattern of the garment does not fit the body.

Model 1:
No wrinkles.

Model 2:
Wrinkles.

Figure 3: A physical model of **Figure 2** demonstrating wrinkling on a hyperbolic surface.

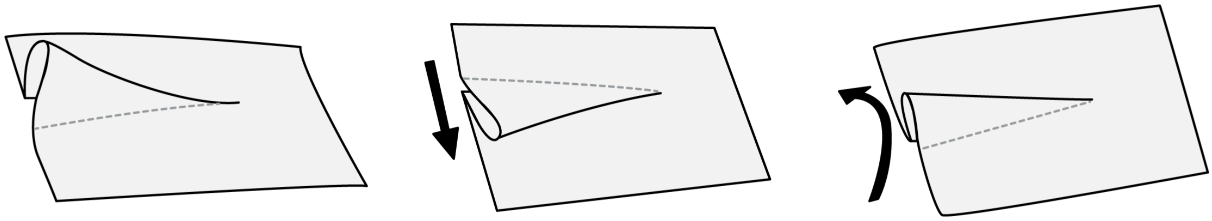


3D wrinkle pattern.

The flat pattern created by the fabric making contact with the body.

Figure 4: The part of the pattern that makes contact with the body creates a pattern of the garment, while the wrinkles indicate where there is excess fabric.

Set 2:



Model 3:
A dart that has been sewn into place.

Model 4:
A temporary folded structure is created when the fabric wrinkles.

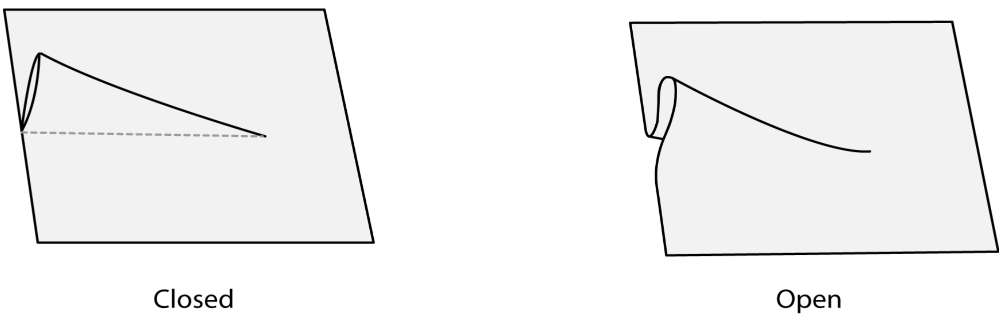
Model 5:
This temporary folded structure behaves in the same way as a dart sewn in place.

Figure 5: Wrinkles create temporary structures that behave like darts, but are not sewn together.

Model 3 Model 4 Model 5

Figure 6: A physical model of **Figure 5**.

Observations can now be made about the wrinkle structures in relation to the dart structures. The wrinkle structures are almost identical in structure and form to the darts. The only difference is that the darts are permanently sewn in shape. From a geometric point of view they are identical and have the same structure and function. Darts sewn in shape can be considered closed darts, while wrinkles, as open darts, temporarily hold a dart shape. The research thereby sees that techniques such as contour manipulation can be used to analyse wrinkles.

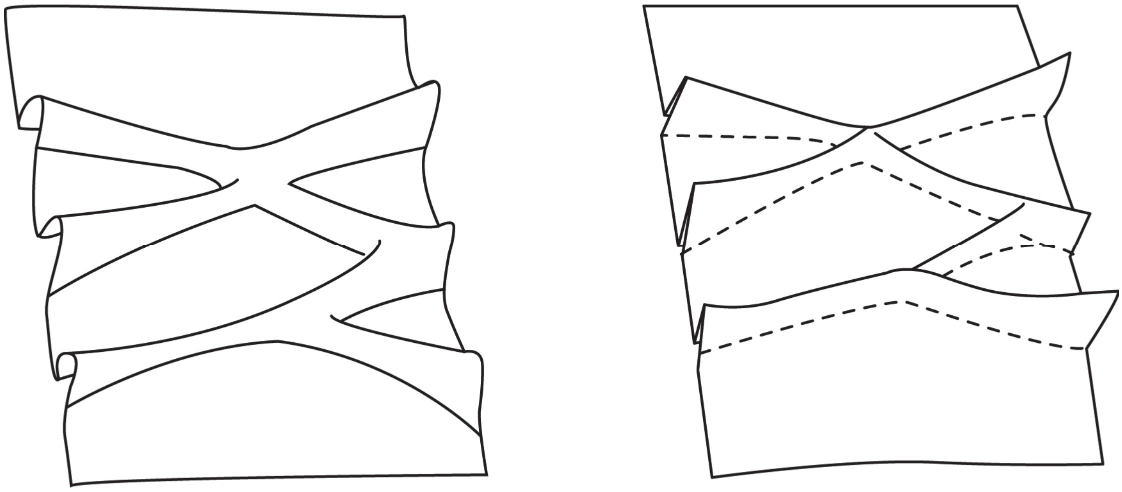


Close ended darts.

Open ended darts.

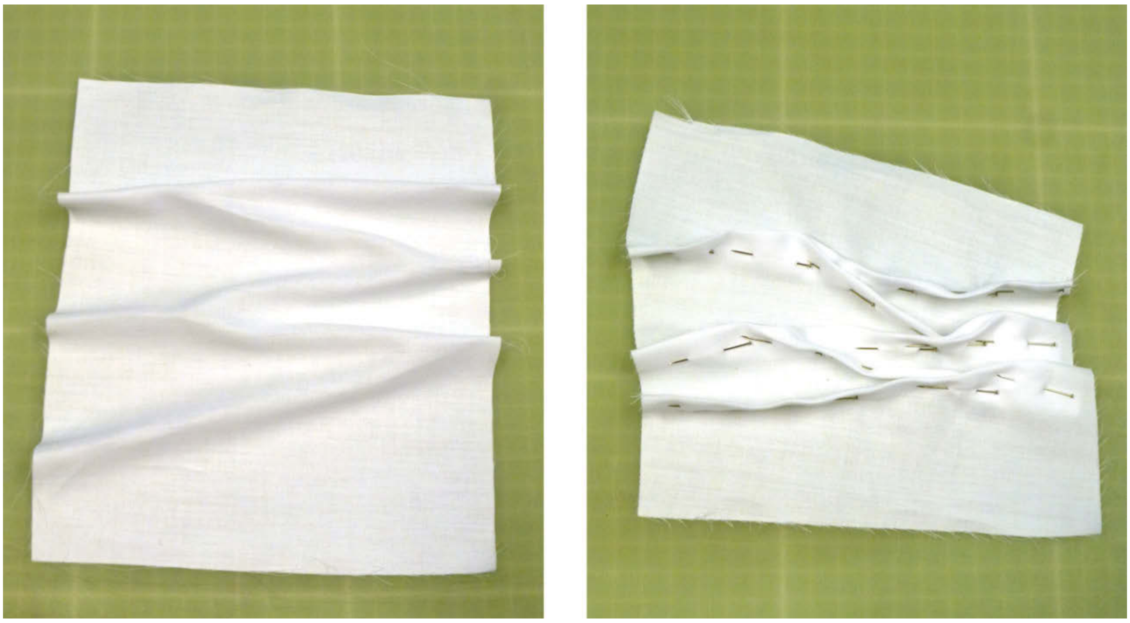
Figure 7: Open-ended darts change the shape of a garment like a dart, but are temporary structures and are not sewn together like a closed-ended dart.

Set 3:



Model 6 Model 7

Figure 8: Take the wrinkle pattern and pinch out all the wrinkles into a series of darts, gussets and contours.



Model 6 Model 7

Figure 9: A fabric model of **Figure 8.**

It is observed from this pattern that wrinkle structures can be held in place and analysed as a complex series of darts gussets and contours.

Conclusion

The experiment shows that wrinkles are distinct patternmaking structures that can be carefully mapped to gain information about the body fit. Wrinkles may be temporary structures, but they can be flattened and analysed like patterns that are sewn together. They can also occur in predictable shapes, and this makes it possible to deconstruct a complex wrinkled pattern into a series of simpler patterns.

Experiment 42: Wrinkle Analysis, Part 2

Rationale

This experiment analyses wrinkles as complex patternmaking structures that can be objectively measured and recorded. When wrinkles are created on the body they tend to form structures with similar shapes. At first these patterns may look overwhelmingly complex, but they can be deconstructed and analysed as a series of smaller structures. This experiment examines common wrinkle structures and explores how the patterns can be used to observe the underlying shape of the body.

Hypothesis

The research anticipates that complex wrinkle structures can be deconstructed into smaller units. By understanding these patterns it learns about the body shape that the wrinkle lies on.

Experimental Design

The first part of the experiment examines commonly-generated wrinkle shapes and how they can be combined to create complex shapes. Some of these include "X", "Y" and zigzag-shaped wrinkles. It also looks at crescent shaped, "S" shaped and "Z" shapes. Wrinkles that seem complex, when deconstructed into these smaller units, are easily mapped.

The second part takes a wrinkle pattern off the sleeve of a garment and deconstructs it into a series of smaller wrinkle patterns. These are then analysed to reveal the shape of the body.

Procedure

<u>Part 1</u>: Common wrinkle shapes on the body

Set 1:

The experiment starts with rectangular pieces of fabric of standard size. These are draped into the shapes of wrinkles that commonly occur. Then analyse the form and structure of their patterns: Analyse the shape of the wrinkle. Shade in grey the surface that touches the body, and shade in blue the part of the fabric that creates the wrinkle.

Model 1: Drape a pattern which creates a "Y" shaped wrinkle.

Model 2: Drape a pattern which creates an “X” shaped wrinkle.

Model 3: Drape a pattern which creates a zigzag-shaped wrinkle.

Set 2:

The second set of iterations follows the same procedure, this time analysing wrinkles that are crescent-shaped, “S” shaped and “Z” shaped.

Model 7: Drape a pattern which creates a crescent-shaped wrinkle.

Model 8: Drape a pattern which creates an “S” shaped wrinkle.

Model 9: Drape a pattern which creates a “Z” shaped wrinkle.

Part 2: Using Wrinkles to map the body

The second part of the experiment uses wrinkles to map the body shape. A complex set of wrinkles is taken off the body. Their patterns are then deconstructed into smaller units, this makes it easier to analyse them. They can in fact reveal the underlying shape of the body.

Set 3: Using wrinkles to map the body

Model 10: Start with the sleeve pattern of the body.

Model 11: Bend the arm so that the sleeve wrinkles.

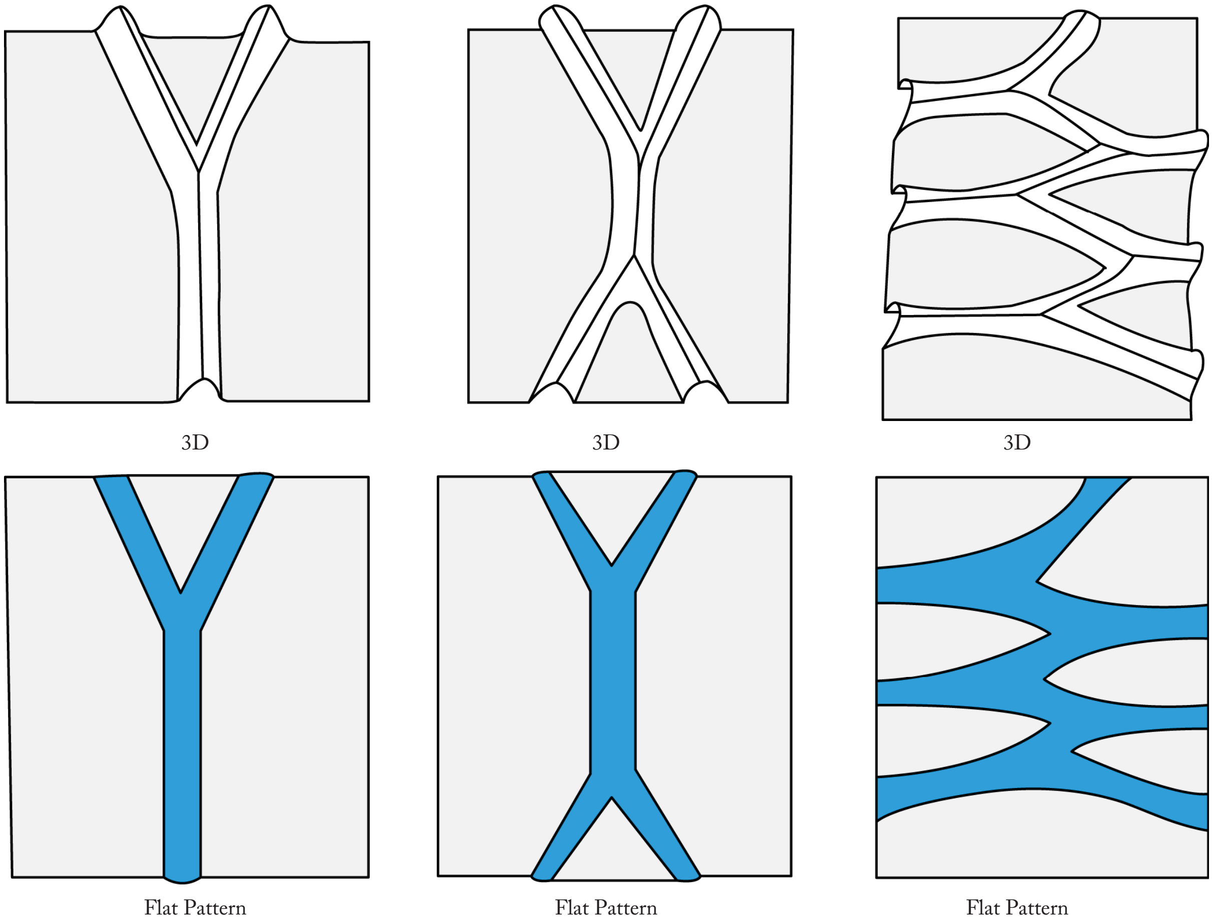
Model 12: Analyse the shape of the wrinkle created by the sleeve. Cut out a rectangular part of the sleeve where the wrinkle pattern occurs. Shade the pattern that makes contact with the body in grey and the part of the pattern that forms the wrinkles in blue.

Model 13: Deconstruct the wrinkle pattern into smaller shapes of wrinkles.

Model 14: Take the dart pattern from model 12 and separate the pattern onto the part of the pattern that makes contact with the body, and the fabric that makes the wrinkle.

Model 15: Take the parts of the pattern that make contact with the body and sew them together. This should form a pattern that re-creates the shape of the body the fabric was resting on.

Set 1:



Model 1:

"Y" shaped wrinkle.

Model 2:

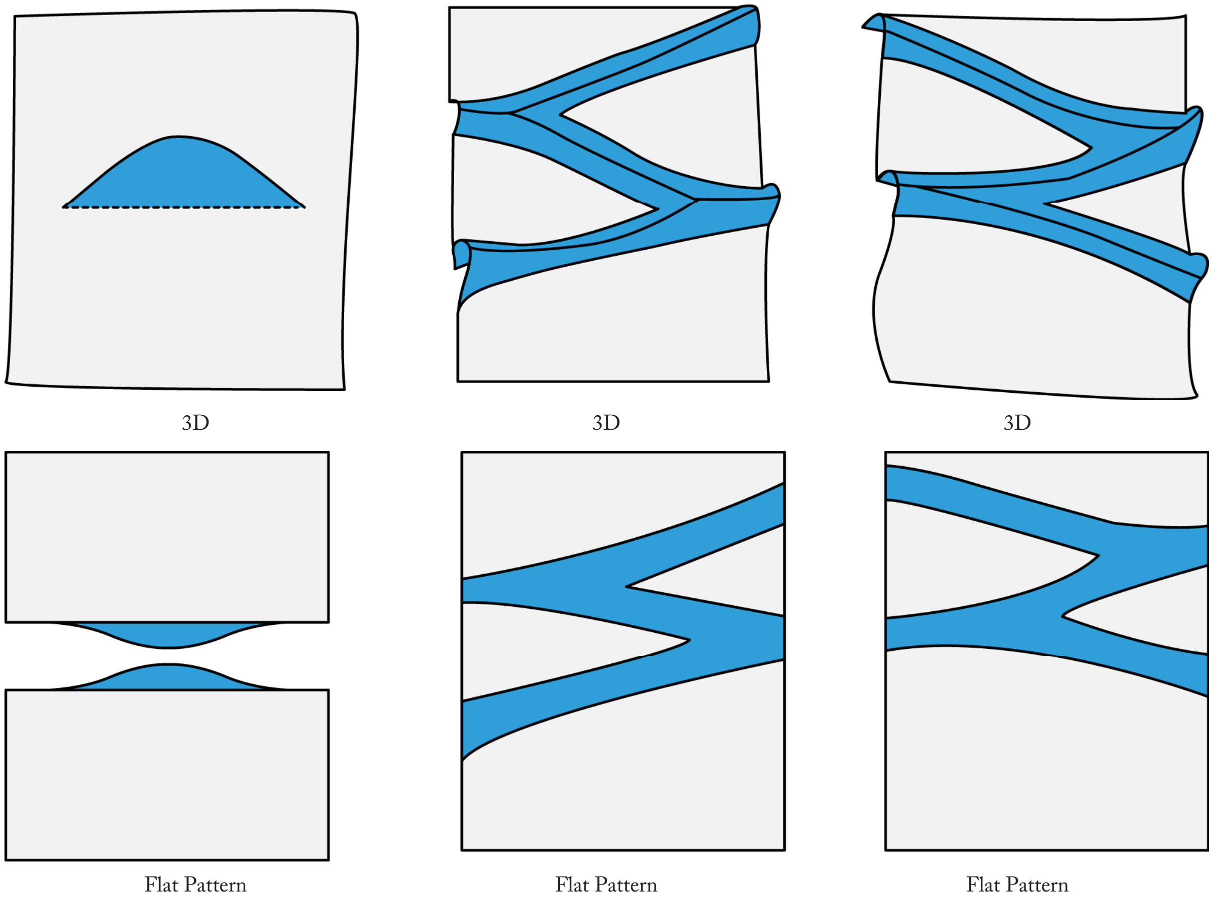
"X" shaped wrinkle.

Model 3:

"Zigzag" shaped wrinkle.

Figure 1: "X", "Y" or "zigzag" - shaped wrinkles. The part of the pattern that makes contact with the body is shaded in grey while the part of the pattern the forms the wrinkle is shaded in blue.

Set 2:



Model 7:

A crescent shaped wrinkle.

Model 8:

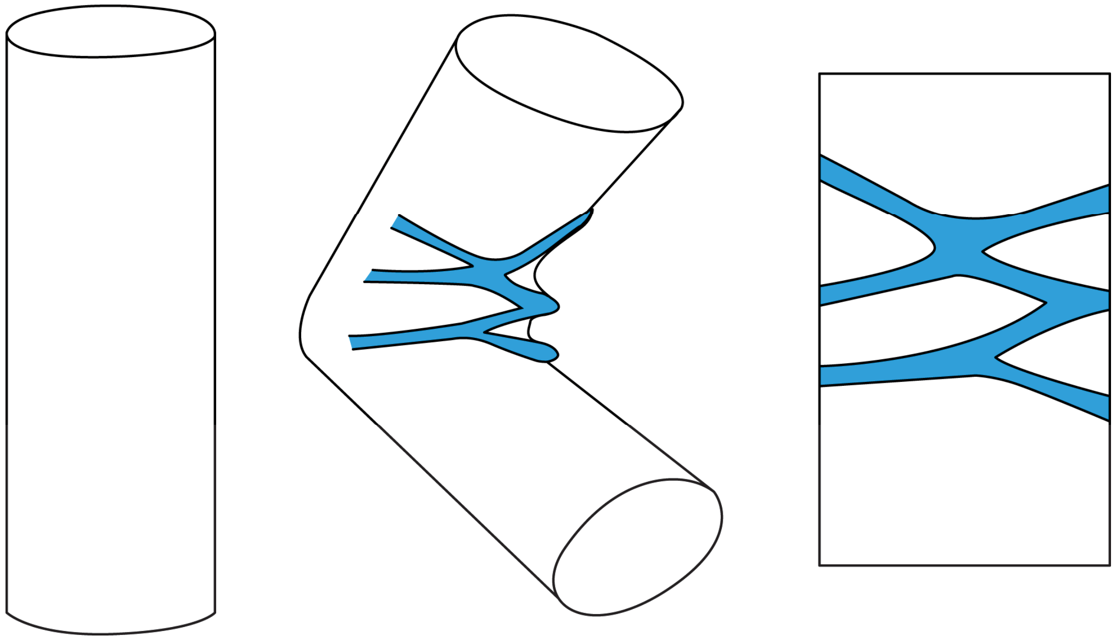
An “S” shaped wrinkle.

Model 9:

A “Z” shaped wrinkle.

Figure 2: Wrinkles create different shapes.

Set 3:

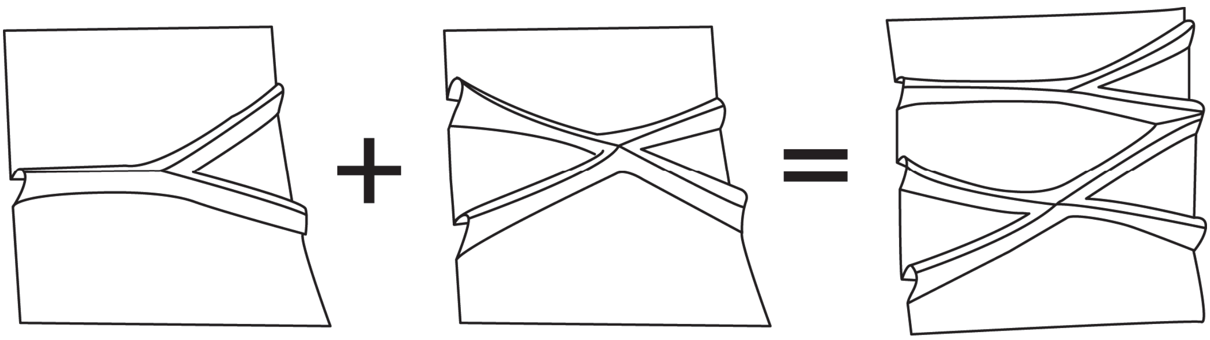


Model 10:
A cylindrical pattern.

Model 11:
The cylindrical pattern wrinkles as the joint bends.

Model 12:
The flat pattern of the wrinkled shape.

Figure 3: It is observed that when a cylindrical- shaped pattern encloses a bending joint, a zigzag pattern of wrinkles is often created.



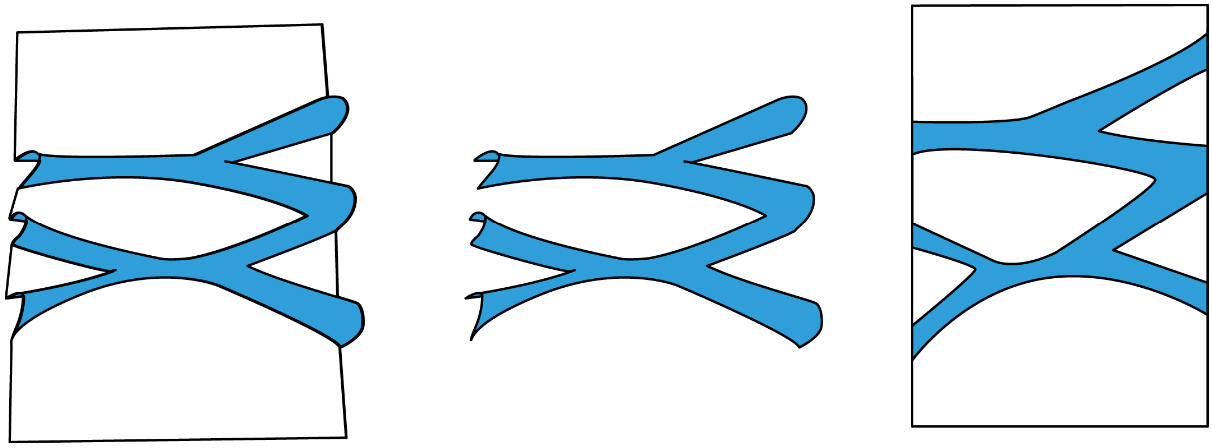
A "Y" shaped wrinkle.

An "X" shaped wrinkle.

The wrinkle pattern.

Model 13

Figure 4: These patterns are a series of "Y" and "X" darts joined together. "Y" and "X" shaped structures create shapes with multiple darts.



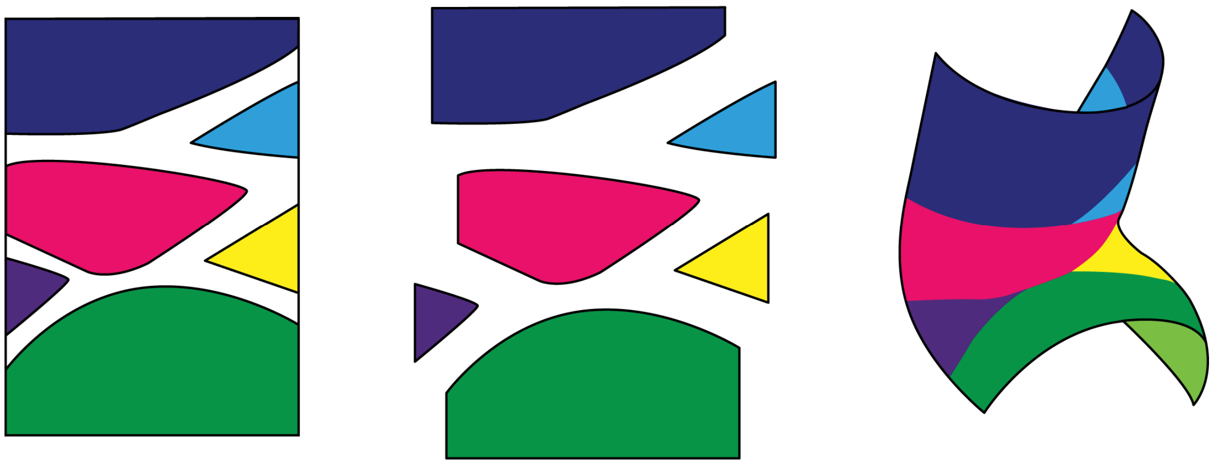
The wrinkle.

The fabric that forms the wrinkle.

The fabric that touches the body.

Model 14

Figure 5: Separate the part of the wrinkle that makes contact with the body from the part of the pattern that creates the wrinkle.



The wrinkle pattern.

The pieces in contact with the body.

Sew together the piece to create the underlying shape of the body.

Model 15

Figure 6: Taking the shapes of the fabric that make contact with the body, it is possible to create a pattern of the body shape the fabric is lying on.

Conclusion

The experiment shows that wrinkles are distinct patternmaking structures that can be mapped to gain information about the body fit. Wrinkles may be temporary structures, but they can be flattened and analysed like patterns that are sewn together. They also occur in predictable shapes, allowing them to deconstruct complex wrinkled iterations into a series of simpler patterns.

13. Measuring Non-Euclidean Measurements

Experiment 43: **Non-linear measurements**

Experiment 44: **Rigid measurements**

Experiment 45: **Angle measurements in patterns**

Experiment 46: **The drape measure**

Experiment 47: **Measurements on a sphere**

Aim

This group of experiments introduces concepts from Non-Euclidean geometry to record the three-dimensional curvatures of the body, thereby enhancing the accuracy of traditional techniques of linear measurement. The latter clearly have always been limited in their ability to record curvatures since they are incapable of recording the curvature of Non-Euclidean surfaces, working as they do on flat Euclidean surfaces.

Method

The first experiment questions the process patternmakers use for taking measurements off the body, demonstrating that linear measurements are incapable of recording the body's three-dimensional curvature. The second experiment shows how common configurations of linear measurements can slide and pivot, causing loss of accuracy. The third addresses the importance of angle measurements in shaping the garment, and the fourth introduces a new tool called the "drape measure", that makes it easier to take angled measurements. The final experiment shows the incompatibility of flat Euclidean measurements to curved Non-Euclidean surfaces. It tests different approaches using linear and angle measurements to create a flat triangular pattern lying on a spherical surface.

Analysis

These experiments address the limitations of linear measurements and offer ideas from Non-Euclidean geometry to improve traditional patternmaking techniques. Clearly, a single linear measurement is incapable of capturing the shape of the curvature of the surface. For this, it requires angle measurements. Tools such as tape measures cannot capture these, so a new device called a "drape measure" is required to capture the angle measurements of an apex point.

In fact, combinations of linear and angle measurements are required to record curved surfaces. Configurations of linear measurements taken from the body can form grid patterns. However, these rectangular grids, unlike triangles, are not rigid shapes. Such a non-rigid shape can sheer and pivot, reducing the accuracy of the measurement, whereas taking measurements off the body that form an array of triangles can improve accuracy. In sum, a combination of linear and angle measurements is the most effective way to draft patterns off the body.

Experiment 43: Non-Linear Measurements

Rationale

This experiment demonstrates the limitations of taking linear measurement on the three-dimensional form of the body, owing to the fact that they are Non-Euclidean.

Hypothesis

The research anticipates that using principles of Euclidean geometry to take Non-Euclidean measurements, limits their accuracy.

Experimental Design

This experiment shows some limitations in mapping the three-dimensional form of the body using linear measurements. Patternmakers cannot measure the most important element: the curvature. The first part of the experiment shows that linear measurements taken off the body are actually curved measurements. The second part demonstrates how linear measurements can represent surfaces of many shapes, but do not give any information about the curvature of the surface. The third part shows that angles are difficult to measure using linear measurements.

Procedure

Part 1:

Model 1: Drape a pattern for the front and back of the garment on a mannequin. On the garment draw in different colours the linear measurements that a patternmaker would take off the body. Draw linear measurements across the chest, at bust, waist and hip and waist level.

Model 2: Take the draped garment off the body and analyse the front and back pattern of the garment.

Observe how these curved body measurements have become linear measurements.

Part 2:

The second iteration takes a linear measurement and draws the same distance on different-shaped surfaces.

Model 3: Measure a linear measurement of standard length (length X) from point A to point B on a flat Euclidean surface.

Model 4: Create a flat Euclidean surface and draw a line of length “X”.

Model 5: Create a curved Euclidean surface and draw a line of length “X”.

Model 6: Create a Euclidean surface. Bend the surface so it is in a wave shape. Draw a line of length “X”.

Model 7: Create a hyperbolic-shaped surface. Draw a line of length “X” on the surface.

Model 8: Create a spherical-shaped surface. Draw a line of length “X” on the surface.

These patterns all have the same linear measurement, but are very different shapes. Observe the differences in shape created by a single linear measurement.

Part 3:

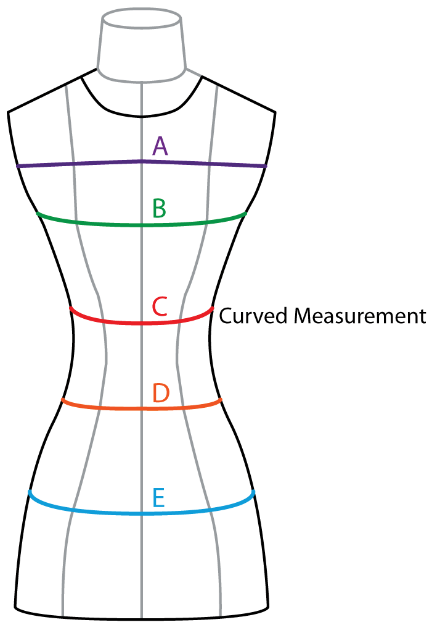
The third iteration points out the difficulty of measuring angles with linear measurements. Patternmakers have a limited ability to measure the curvature of a surface without measuring the number of angles in a pattern. It takes linear measurements off the body, but it is difficult to take angle measurements. The research compares the difficulty of taking an angle measurement with a tape measure compared to using a protractor.

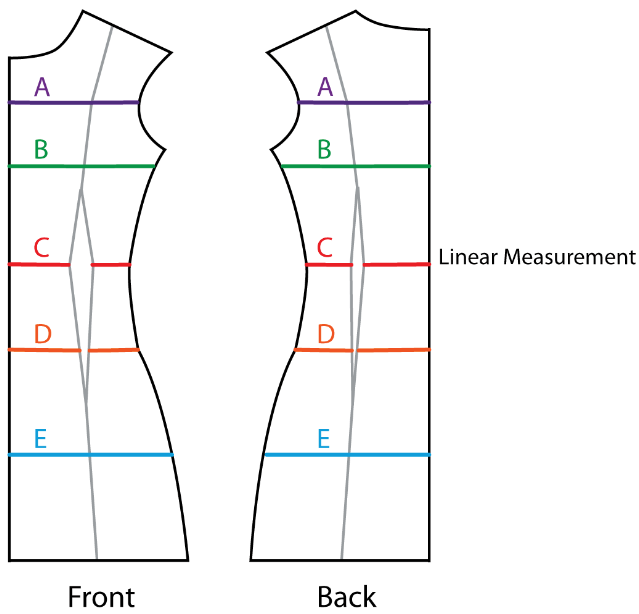
Model 9: Create a rectangular pattern with a single straight-edge dart at its centre. Try to measure the dart angle using linear measurements.

Model 10: Take the same dart pattern and measure the dart angle using a protractor.

Results

Part 1:





3D Form

Flat Pattern

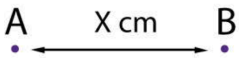
Model 1

Model 2

Figure 1: Tape measures take curved measurements off the body and translate them into linear measurements on a flat pattern.

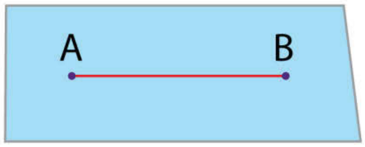
It is observed that even though these measurements are linear, they are still curved when measured on the body.

Part 2:



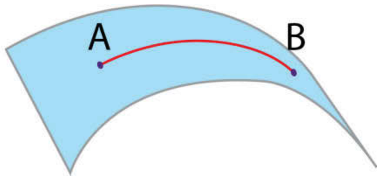
Model 3:

Linear measurement.



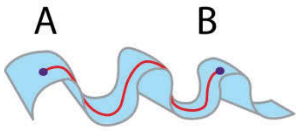
Model 4:

Linear measurement of a flat surface.



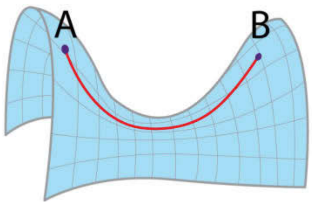
Model 5:

Linear measurement of a curved flat surface.



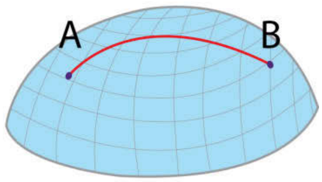
Model 6:

Linear measurement of a curved flat surface.



Model 7:

Linear measurement of a hyperbolic surface.



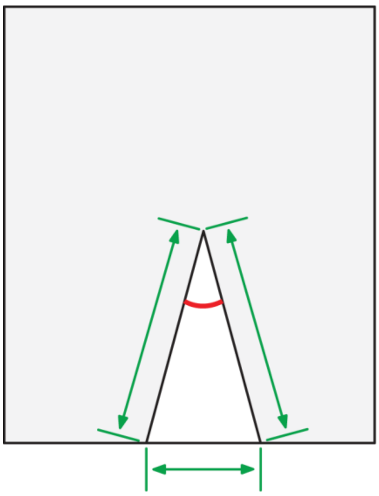
Model 8:

Linear measurement of a spherical surface.

Figure 2: Linear measurements are fundamentally limited in their ability to measure a curved surface. A single linear measurement is incapable of recording the surface's complex three-dimensional curvature.

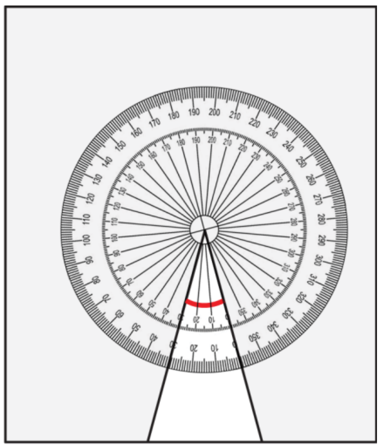
It is noted that the same linear measurement can represent a pattern with many different shapes of curvature. A linear measurement has no way of recording the curvature it lies on.

Part 3:



Model 9:

Measuring an angle with linear measurements.



Model 10:

Measuring an angle with a protractor.

Figure 3: Measuring an angle with linear measurements compared to using a protractor.

It is observed that it is very difficult to take a linear measurement with a tape measure. On order to find out the angle, the patternmaker would have to measure all the lengths of the dart, construct a triangle and use trigonometry to work out the angles. A protractor is a much more convenient instrument for measuring dart angles.

Conclusion

The experiment shows that it is not possible to record the curvature of a surface using a linear measurement. The same linear measurement can represent many different surfaces with different geometries. The process of measuring the curvature of a pattern requires an angular measurement. It is difficult to take an angular measurement using a tape measure, but easy to measure with a protractor.

Experiment 44: Rigid Measurements

Rationale

This experiment shows that linear measurements taken off the body can lose accuracy. When multiple linear measurements are taken off the body they form rectangular grids. Rectangular formations are not rigid structures and can pivot. Formations such as triangles are more stable as they do not pivot. The experiment thereby explores how measurement structures that pivot can lose accuracy.

Hypothesis

The research anticipates that measuring linear measurements on the body forms rectangular grids, and that it is easy for these sets of measurements to pivot, reducing the accuracy of the original measurement.

Experimental Design

To begin, it explores the ways that structures of different shapes can pivot. Secondly, it demonstrates how pivoting patterns affect the accuracy of the measurements.

Procedure

The first iteration compares structures of different shapes to see if they are rigid. Rigid structures cannot pivot at their joints, while non-rigid structures can pivot, deforming their structure.

Part 1:

Model 1: Create a rectangular structure from rods with rotating hinges to test the structural integrity of the shape. Push the top part of rectangle to the right hand side to see if the pattern can pivot.

Model 2: Create a pentagonal structure from rods with rotating hinges to test the structural integrity of the shape. Push the top part of rectangle to the right hand side to see if the pattern can pivot.

Model 3: Create a triangular structure from rods with rotating hinges to test the structural integrity of the shape. Push the top part of rectangle to the right hand side to see if the pattern can pivot.

Observe the properties of these structures and note the structures that are rigid compared to those that pivot.

<u>Part 2</u>:

The second iteration shows how the configurations of measurements can form rectangular structures. It examines how these structures can pivot and how this affects the accuracy of linear measurements.

Model 4: Start with a mannequin and mark in red commonly-measured linear measurements on the surface. Observe how these patterns create rectangular grid patterns.

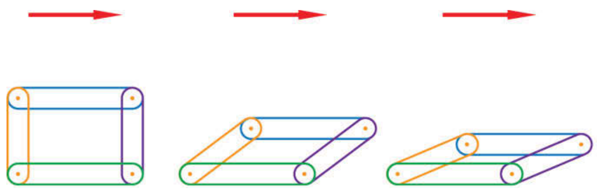
Model 5: Start with a mannequin and draft commonly-measured linear measurements from Armstrong's patternmaking text book (2010, pp. 34 - 35). Observe the number of rectangular structures compared to triangular ones.

Model 6: Start with a mannequin and draw key body measurements on the pattern such as bust, waist and hip measurements. Use coloured string to represent the different measurements taken. Pivot the rectangular structure to demonstrate how a small inaccuracy in one measurement can affect several.

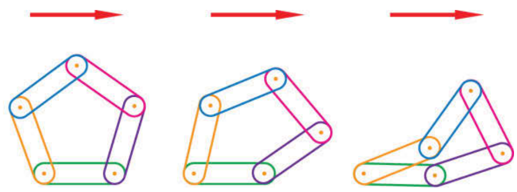
Model 7: Wrap a coloured piece of string around the bust point of a mannequin to represent a linear measurement. Pivot the linear measurement to show how pivoting a measurement can affect the accuracy of the garment around it.

Results

Part 1:



Model 1:
Rectangles and squares are not rigid structures.
They can pivot and shear into different shapes.



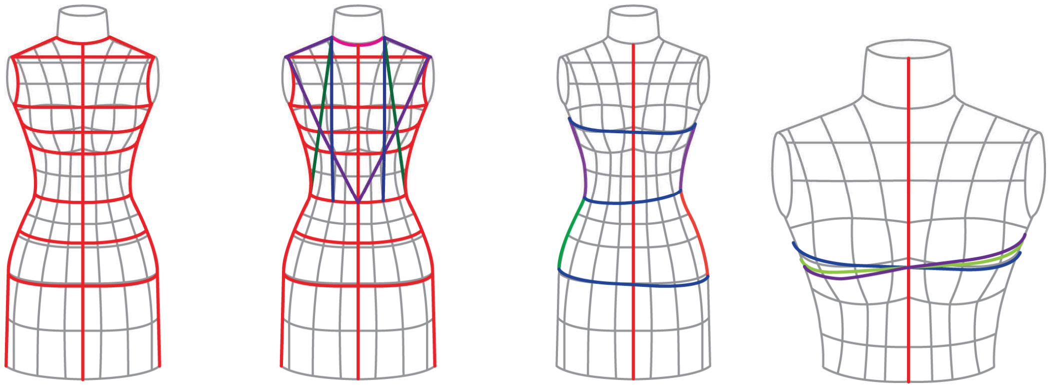
Model 2:
Shapes with more sides such as pentagons
can pivot and shear into different shapes.

Model 3:
Triangular structures are rigid and their shapes cannot pivot or shear.

Figure 1: Squares, rectangles and pentagons are not rigid structures and can shear and pivot. Triangular structures are rigid and do not shear or pivot. This makes taking triangular-shaped measurements more accurate.

It is observed that squares, rectangles and pentagons are not rigid structures and can shear and pivot, while triangular structures are rigid and do not shear or pivot. This makes triangular-shaped measurements more accurate, as rigid structures cannot pivot.

Part 2:



Model 4:
Measurements taken around the body form a rectangular grid.

Model 5:
More complex measurement systems create measurements that can pivot.

Model 6:
Key body measurements form a rectangular grid which can easily pivot and shear.

Model 7:
Any point on a linear measurement can pivot and reduce accuracy.

Figure 2: The majority of linear measurements form rectangular grids around the body. Rectangular structures can pivot and shear, reducing the pattern's accuracy. At any point, the measurement can pivot, which reduces the accuracy of the measurement.

It is noted that most of the linear measurements taken off the body create a rectangular grid. More complex configurations of measurements such as in model 5 have more triangular structures and are more rigid. Yet there are still many parts that are not rigid. From model 6 and 7 it becomes apparent that it is possible to make mistakes and pivot the garment's measurements. A mistake in a single measurement will likely create inaccuracies in multiple measurements.

Conclusion

Certain configurations of measurements form structures that are not rigid and can pivot. These patterns can lose accuracy if the linear measurement pivots when taken off the body. Ideally, all measurements should be configured in a rigid structure of triangles, reducing the possibility of measurements pivoting and losing accuracy.

Experiment 45: Angle Measurements in Patterns

Rationale

This experiment shows that while most points on a pattern have 360˚, there are critical points on a pattern that determine the form of the garment, namely the apex points of darts, gussets or contours.

Hypothesis

The research anticipates that it can differentiate the critical points that shape the garment by measuring the angle measurements at different points. The critical apex points should have an angle measurement of less than 360˚.

Experimental Design

The experiment is designed to find the critical apex points that determine the curvature of a block pattern. This is achieved by measuring the surface and differentiating the points that have an angle measurement of 360˚, compared to angles with less than 360˚.

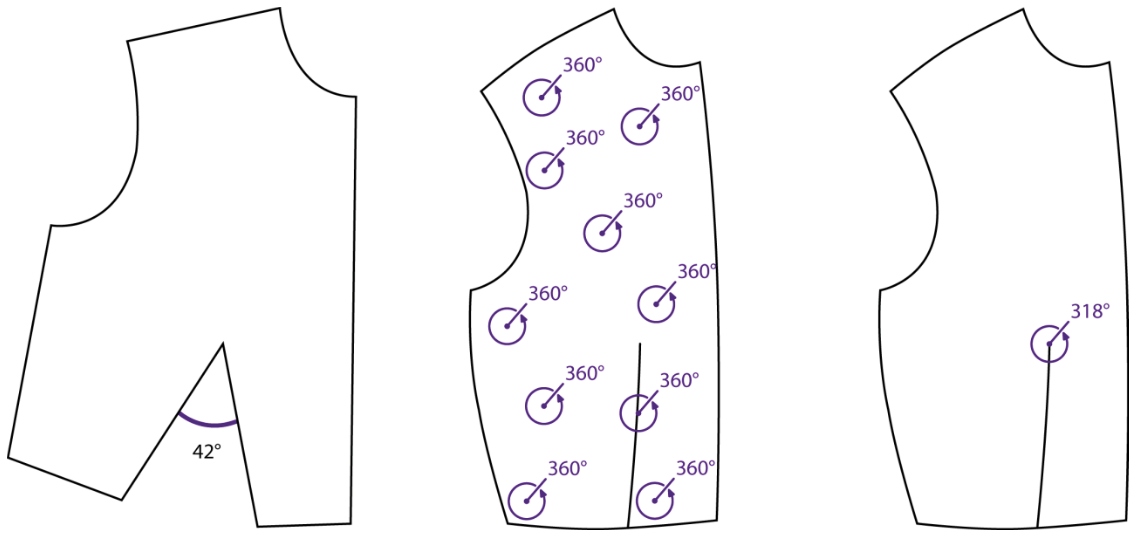
Procedure

Model 1: Create a front block pattern with a dart at the waist with an angle of 42˚.

Model 2: Construct the pattern in 3D. Pick any point on the surface except the dart apex point, and measure the total angles on the surface using a protractor. The different points should all have a measurement of 360˚.

Model 3: Measure the dart apex point using a protractor.

Results



Model 1:
The flat pattern.

Model 2:
The 3D pattern.
Almost every point measures 360°.

Model 3:
The 3D pattern.
Only at the apex point does the pattern measure less than 360°.

Figure 1: In a flat pattern only, with a protractor, almost every point measures 360°. Only at the apex point is the measurement less than 360°.

Conclusion

The experiment reveals critical shaping points that determine the three-dimensional shape of the garment. The majority of the points of the pattern are uniform and do not change the form of the garment, but there are points that do significantly shape the pattern. This applies as much to flat patterns as it does to patterns constructed in 3D. This means that it is equally effective to measure angles directly off the body when they are being measured.

Experiment 46: The Drape Measure

Rationale

This experiment demonstrates the ability of the "drape measure" device to measure the angles of a pattern off the body. When taking measurements off the body, linear measurements have a limited ability to record the three-dimensional form. Measuring the curvature of the body is achieved by taking angle measurements off the body. This adds a new dimension of measurements to patternmaking. While the tape measure is a device for taking linear measurements, the "drape measure" is a device that measures the angles of cone shapes taken off the body. The experiment shows how the drape measure can be used to gain valuable patternmaking information.

Hypothesis

The research anticipates that the drape measure will measure the cone angle of the pattern off the body or any curved surface.

Experimental Design

The drape measure is used to measure the cone angle of a surface. It is created by joining together two paper print-outs of protractors. This allows the patternmaker to measure a cone of more than 360°. The experiment demonstrates how this patternmaking device works, by showing how it can measure Euclidean, spherical and hyperbolic geometric shapes.

Procedure

A single protractor can make a cone shape with a measurable angle. Two protractors can create a cone angle which is more than 360°. The drape measure measures cone shapes with more than 360° and less than 360°.

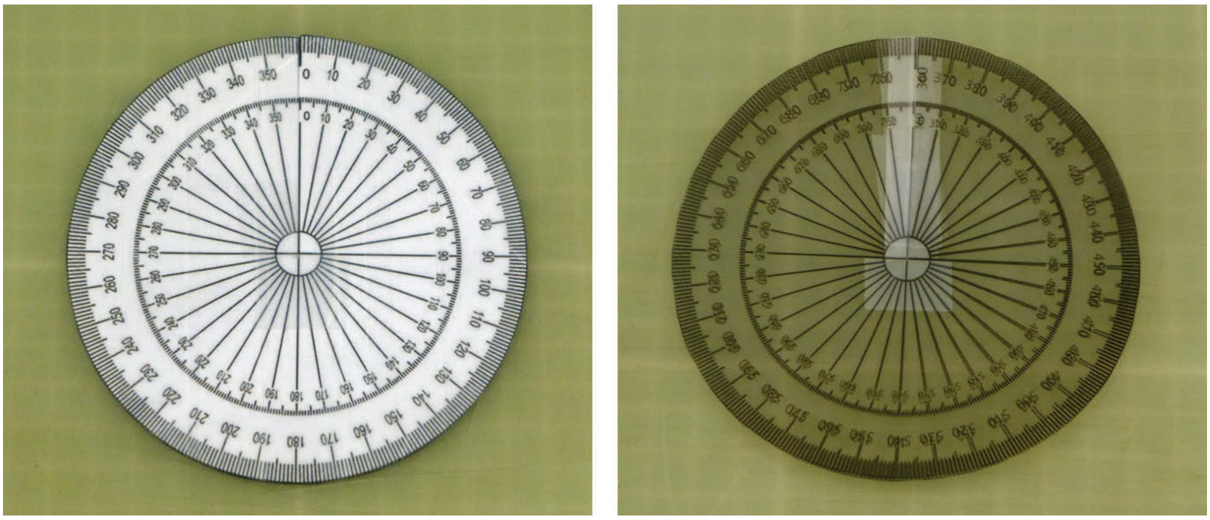
Model 1: Use the drape measure to create a cone angle of less than 360°.

Model 2: Use the drape measure to a flat surface with a cone angle of 360°.

Model 3: Use the drape measure to create a cone angle of more than 360°.

Observe the shapes made by the drape measure.

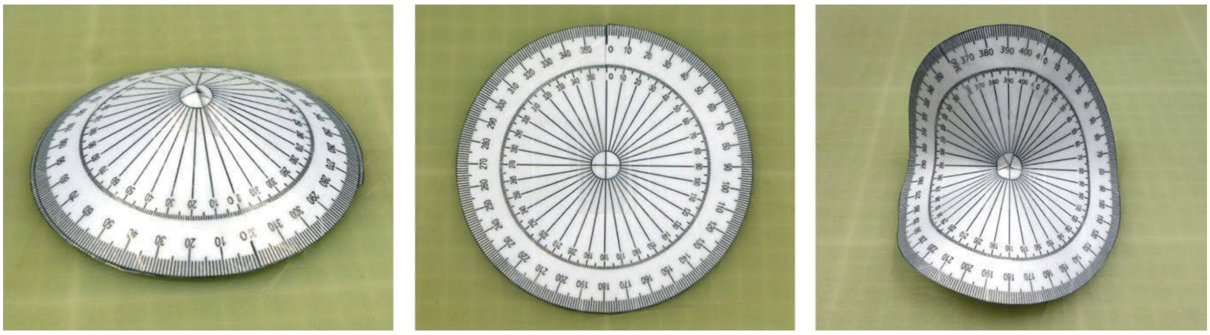
Results



Paper Drape Measure

Plastic Drape Measure

Figure 1: Different versions of the drape measure, made from paper and plastic.



Model 1:

Measure elliptical surfaces.

Model 2:

Measure flat Euclidean surfaces.

Model 3:

Measure hyperbolic surfaces.

Figure 2: The drape measure is a device that can measure the cone angle of the wearer's body.

The drape measure can measure a curved surface.

The bust measurement is often a spherical surface.

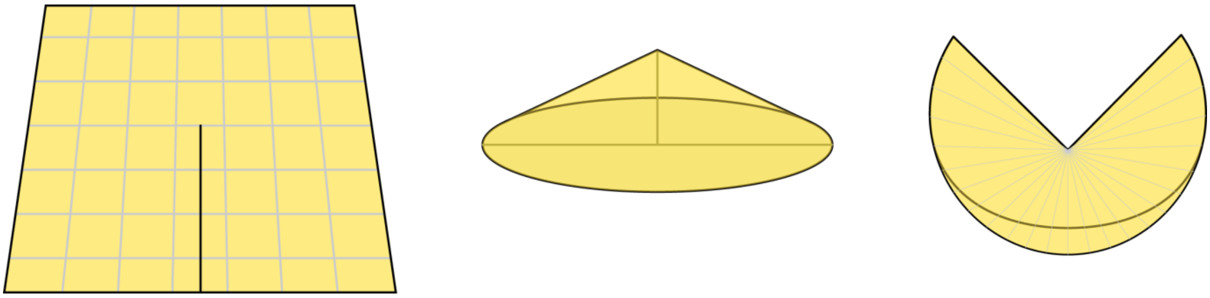
Figure 3: The drape measure is used to measure a spherical surface and interpret it into a cone angle.

The drape measure can measure a curved surface.

The waist measurement is often a hyperbolic surface.

Figure 4: The drape measure is used to measure a hyperbolic surface and interpret it into a cone angle.

Observations:



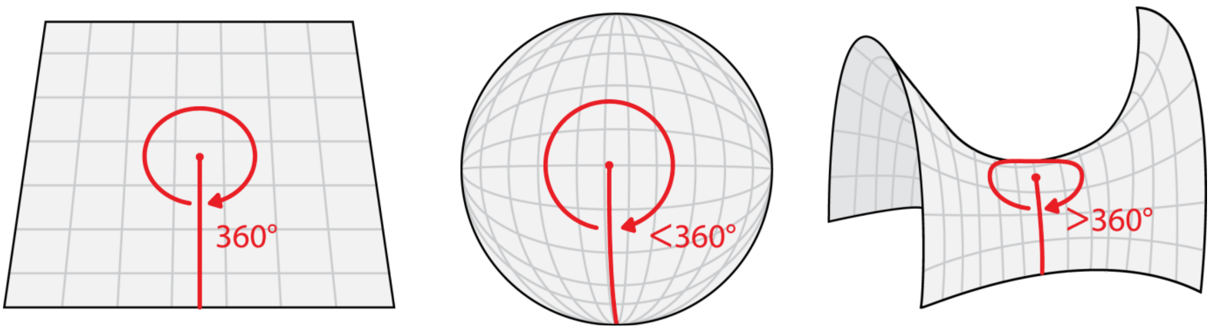
A flat piece of material.
360° in a revolution.

A spherical surface.
Less than 360° in a revolution.

A hyperbolic surface.
Greater than 360° in a revolution.

Figure 5: Different apex points have different curvatures.

It is observed that the drape measure deforms to create a cone of different sizes. The cone angle is less than 360° on a spherical surface, equal to 360° on a flat Euclidean surface and greater than 360° on a hyperbolic surface (see figure 5). When measuring different points on the body, spherical, hyperbolic and Euclidean surfaces will all have different angles (see figure 6). Another way of determining the curvature of a surface over an area, is to draw a triangle on it. Triangles on a flat surface will have 180°, spherical surfaces will have triangles of more than 180° and hyperbolic surfaces will have triangles of less than 180° (see figure 7). The drape measure can be used to take these types of measurement.

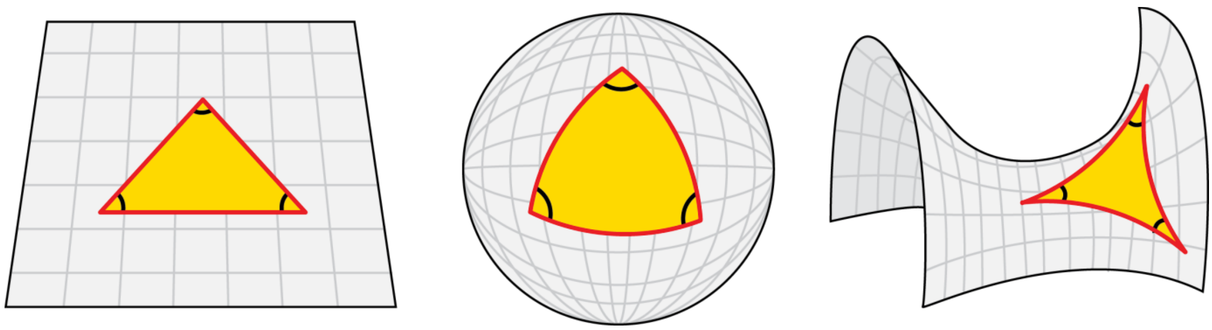


Flat Euclidean

Spherical

Hyperbolic

Figure 6: Measuring the amount of angles on a single point is an effective way of measuring the curvature of the surface.



Flat Euclidean:
Triangles angles = 180°

Spherical:
Triangles angles > 180°

Hyperbolic:
Triangles angles < 180°

Figure 7: Measuring the angles of a triangle is another way to find the curvature of a surface.

Conclusion

The drape measure can effectively record the angle measurement off the body or any other curved surface. It can record spherical, hyperbolic and flat Euclidean forms.

Experiment 47: Measurements on a Sphere

Rationale

This experiment demonstrates the limitation of using linear measurements when measuring curved surfaces. In fashion patternmaking it is a common practise to translate linear measurements taken off the body onto a flat paper pattern. This practise assumes that curved Non-Euclidean measurements can be directly translated onto a flat Euclidean surface. Flat Euclidean surfaces and curved Non-Euclidean surfaces have different geometric properties. Linear measurements are used to capture the form of a sphere. This shows the limitation of linear measurements to record the shape of a three-dimensional surface. The addition of angle measurements can help improve the accuracy of patterns created from linear measurements.

Hypothesis

The research anticipates that taking linear measurements off the sphere has limited ability to capture the three-dimensional form as a flat pattern. The addition of angle measurements should be able to improve the accuracy of the measurement. Draping replicas of the pattern in wire, it should be able to translate some of the curved measurements onto the flat pattern. The combination of linear and angular measurements should deliver a pattern of great accuracy.

Experimental Design

The first part of the experiment takes linear measurements off a sphere and translates the measurements into a flat pattern, comparing the difference between the surface area of the sphere and the area created by the flat pattern.

The second part tries to create a flat pattern from a combination linear measurements and angle measurements. It tests some of the limitations of translating angle measurements onto a flat pattern.

The third part drapes pieces of wire on the sphere that will capture the linear measurement, angle measurements and some of the curvature of the surface.

The fourth part divides the triangle into a series of smaller triangles, using a tape measure and a drape measure to record both linear and angle measurements. These are then drafted into a flat pattern.

It then evaluates the limitations and advantages of each of these approaches.

Procedure

Part 1:

Model 1: Create a sphere with a radius of 5 cm. Measure a circular triangle on the pattern with sides "X", "Y" and "Z". The top of the triangle should be at the top pole of the sphere while the other two parts should be on the equator of the sphere. This shape should form a quarter of a hemisphere and cover 1/8th of the surface of the sphere.

Model 2: Translate linear measurements "X", "Y" and "Z" onto a flat piece of paper. This shape will form a triangle.

Model 3: Calculate the surface area of the triangle on the sphere.

Model 4: Calculate the surface area of the triangle on the flat pattern.

Compare the surface areas of the two triangles.

Part 2:

The second iteration introduces angular measurements in order to increase the accuracy of the measurements. These are taken by using a protractor.

Model 5: Start with the same sphere of 5 cm radius. This time, measure the angles of the triangle.

Model 6: Use the linear measurements combined with the angular measurements to draft the pattern onto a flat piece of paper.

Part 3:

The third iteration acknowledges the difficulty of using linear measurements and angles to record the garment's three-dimensional shape. It drapes a soft wire that copies the form of the sphere. This is a way of translating the curves of the sphere onto a flat pattern. This has limited ability to capture the linear and angle measurements of the triangle.

Model 7: Curve soft wire around the sphere to mimic the shape of the sphere. Use the wire to record the shape of the sphere. This form holds the linear measurement recorded as a curve and the angle measurements.

Model 8: Place the triangle created from wire on a flat piece of paper and then smooth the edges of the triangle until the pattern lies flat.

Model 9: Create a new flat pattern that has the same linear measurements and dart angles, yet where the edges of the triangles are curved.

Part 4:

The fourth iteration attempts to create a flat pattern from a curved surface using a combination of linear and angle measurements. The drape measure is a much more accurate way of recording dart angles on a curved surface as it is able to bend. On a sphere, the total cone angles at any point are less than 360°. To capture the shape of sphere there must be multiple points on the surface where total cone angles are less than 360°. This means that the surface pattern has to be divided into smaller pieces. This experiment deconstructs a curved triangle on a sphere into a series of smaller triangles. These pieces are joined together to form a flat pattern. It then measures the linear measurements with a tape measure, and the angle measurements with a drape measure.

Model 10: Start with the same triangle on a sphere from model 1.

Model 11: The triangle needs to be divided into smaller pieces. Draw three curved lines that divide the triangle into four equal sections.

Model 12: Measure the four curved horizontal lines of the triangle. Divide each line into four equal sections. Connect these points together to create four vertical lines centred on the top of the triangle. This divides the pattern up into sixteen smaller pieces.

Model 13: Take angle measurements at each of the angles and record the total amount of angles on the sphere.

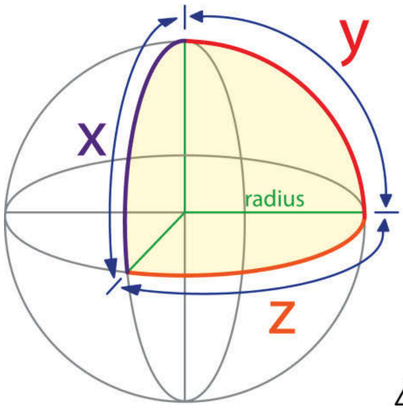
Model 14: Divide the pattern into four vertical strips. Take the linear and angle measurements and draft the patterns as a series of triangles. Join the triangles together to create a flat pattern for part of the overall flat pattern.

Model 15: Join the triangular pieces together to create the flat pattern.

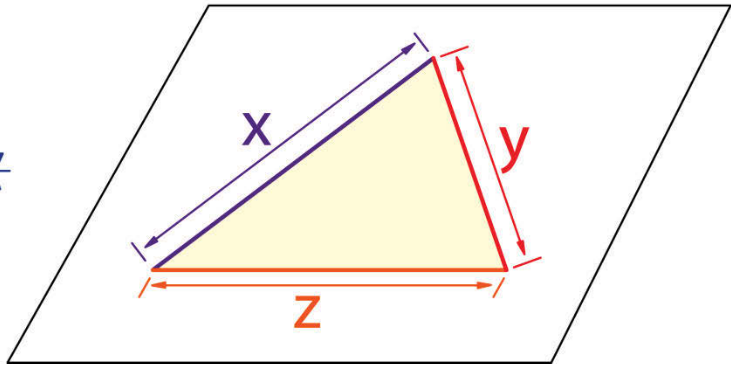
Compare the patterns created by these different drafting techniques.

Results

Part 1:



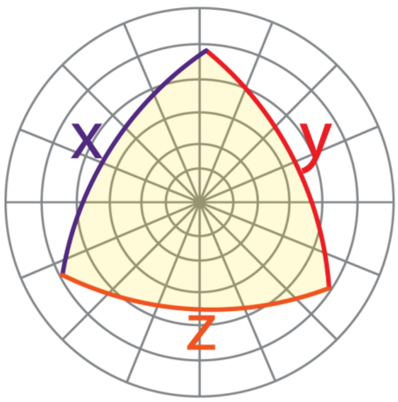
Model 1



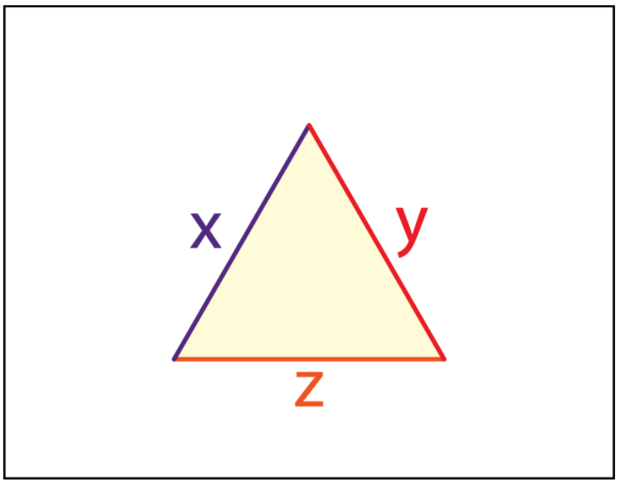
Model 2

Figure 1: Drawing a triangle on a sphere.

Figure 2: The measurements of the sphere were taken and drafted as a flat pattern.



Model 3



Model 4

Figure 3: Drafting a pattern by using measurements taken off a curved surface.

Observations

The area of the triangle on the sphere is not equal to the area of the triangle with the same side lengths on a flat surface.

In this example the area of the area the triangle is $\frac{1}{8}^{\text{th}}$ the surface area of the sphere.

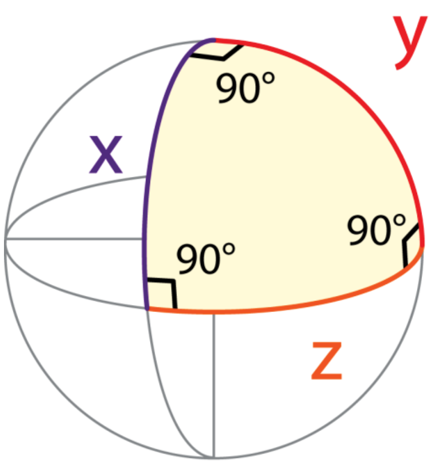
The surface area of the sphere is: Surface area = $4\pi r^2$.

Therefore the Area of Triangle = $\frac{4\pi r^2}{8}$ or $\frac{\pi r^2}{2}$.

The area of the triangle on the flat surface is: Area = $\frac{\sqrt{3}}{4}x^2$. (x is the length of the side of the triangle).

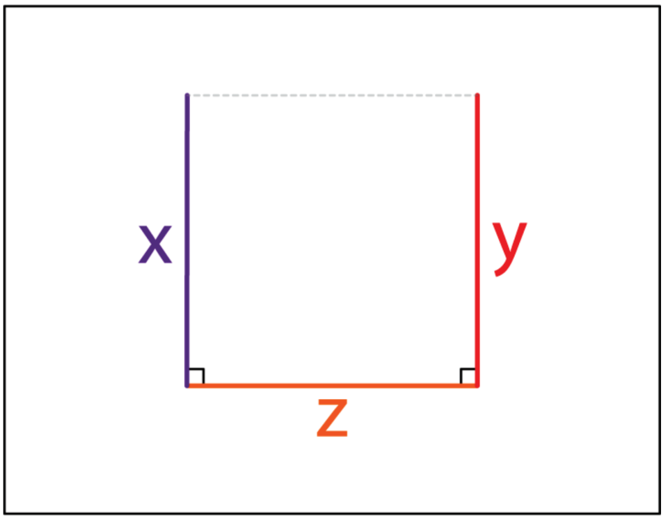
$\frac{\sqrt{3}}{4}x^2 \neq \frac{\pi r^2}{2}$ so the area of the triangle on the sphere is not equal to the area of the triangle drafted on a flat surface. Therefore the pattern is not very accurate.

Part 2:



Model 5:

On this sphere the triangle has angle measurements of 90˚, 90˚ and 90˚. The triangle has a total of 270˚.



Model 6:

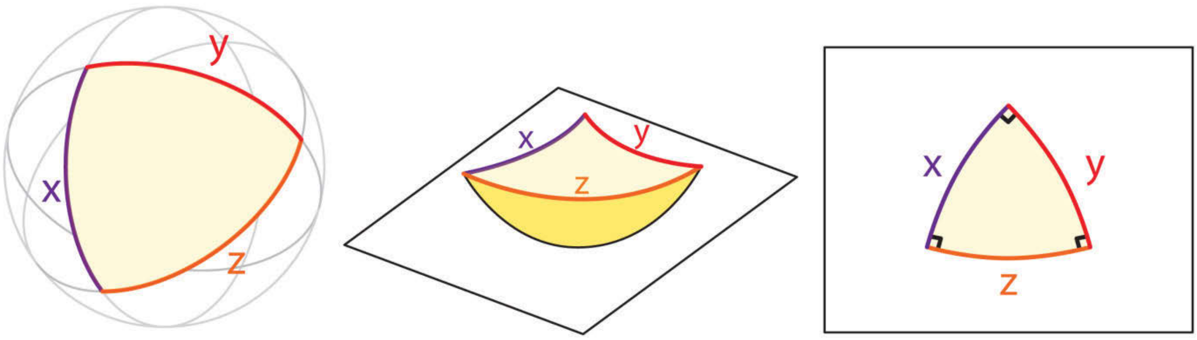
It is not possible to draw the triangle on a flat surface because its angles have more than 180˚.

Figure 4: Taking angle measurements off a triangle on a sphere.

__Observations__

The protractors have limited ability to record the cone angle on the sphere. This is because protractors are flat rigid pieces of material that cannot bend. The total angles of the triangle on the sphere, is more than 180°, making it impossible to draw it on a flat surface, where triangles can only have 180°. One possible solution is that the sides of the triangle are curved. This raises the question of how to measure the curvature.

__Part 3__:



Model 7:
Trace the curve of the sphere using wire.

Model 8:
Take the curved triangle and flatten it on a piece of paper.

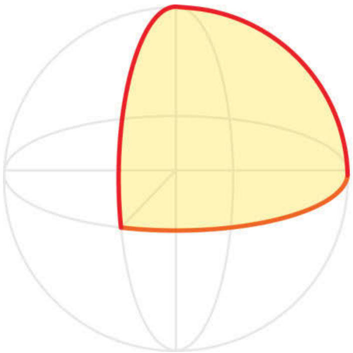
Model 9:
This creates a flat pattern of the three-dimensional shape.

Figure 5: The curved wire taken from the sphere can be flattened on a piece of paper to create a more accurate pattern of the three-dimensional shape.

__Observations__

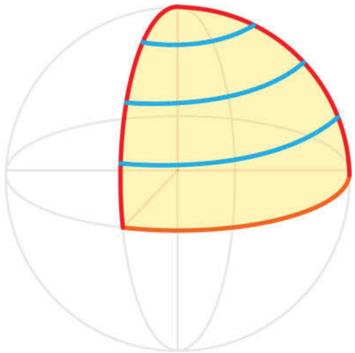
This experiment creates a flat pattern of a triangle with curved edges. This allows a pattern to have the same linear measurement, with the triangle being able to have more than 180°.

Part 4:



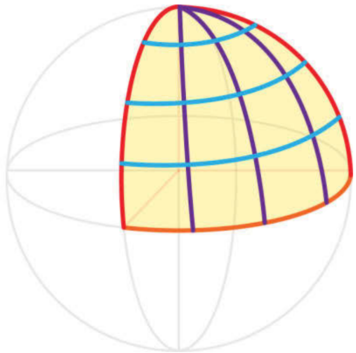
Model 10:

Start with the same triangle on a sphere from model 1.



Model 11:

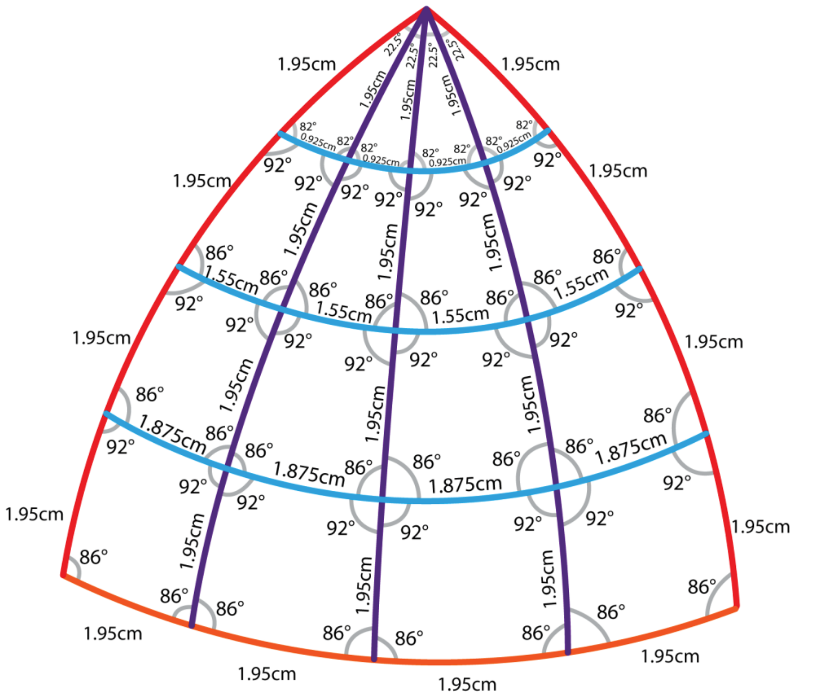
Draw three curved lines that divide the triangle into four equal sections.



Model 12:

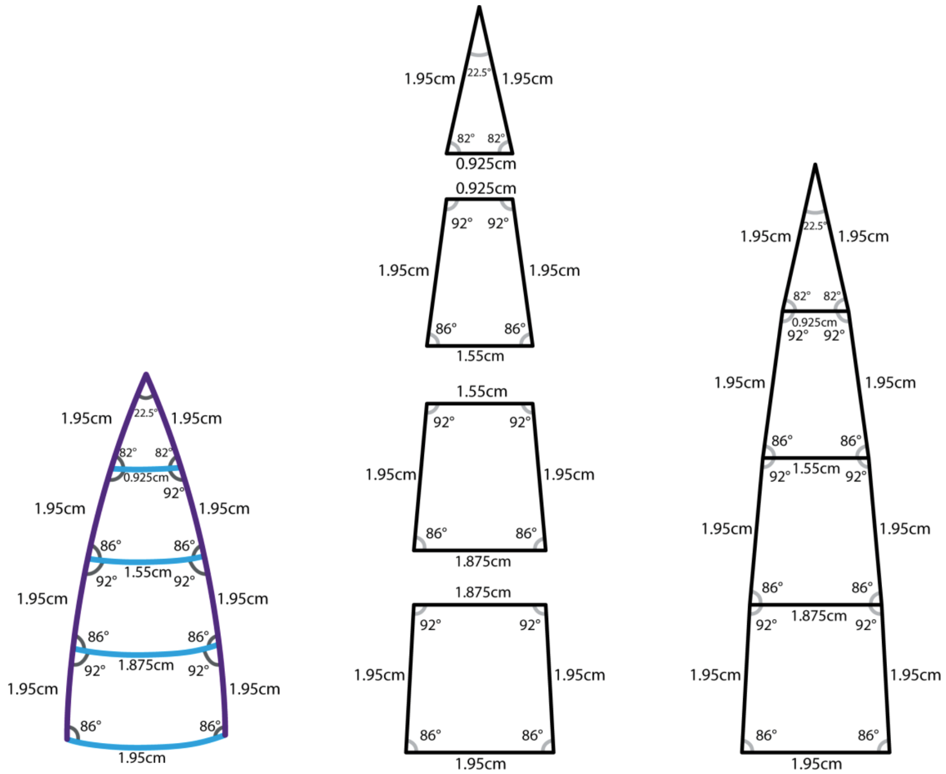
Divide each line into four equal sections. Connect these points together to create four vertical lines centred on the top of the sphere.

Figure 6: The curved wire taken from the sphere can be flattened on a piece of paper to create a more accurate pattern of the three-dimensional shape.



Model 13

Figure 7: Take angle measurements at each of the angles and note the total amount of angles on the sphere.



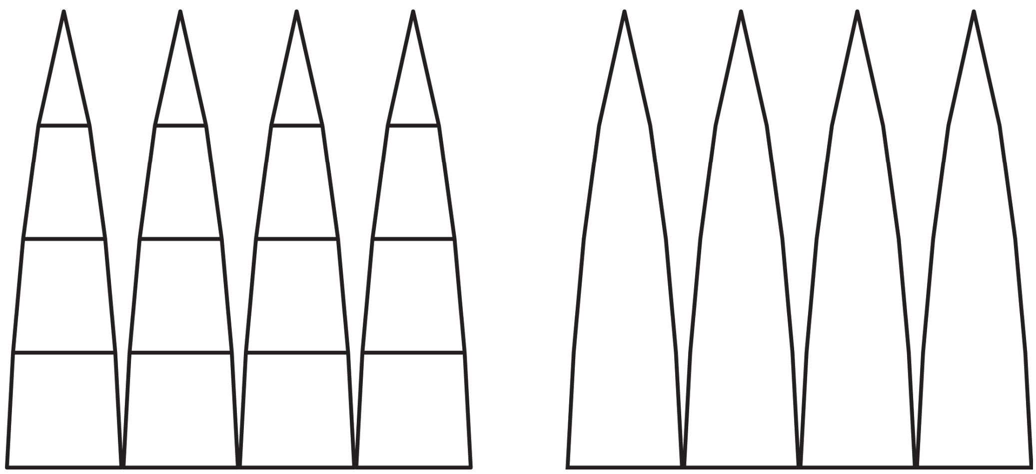
Divide the curved pattern into four identical vertical strips.

Take the linear and angle measurements from the curved pattern and draft them as a series of triangles and trapeziums.

Join the pattern pieces to create the flat pattern.

Model 14

Figure 8: The pattern is divided into four vertical strips. The measurements taken off the triangle are drafted as flat patterns and joined together.



Join the four strips of the pattern together.

The final flat pattern.

Model 15

Figure 9: The final pattern, created by drafting the measurements taken off the triangles and joining the pieces together.

Observations

This way of measuring the pattern creates much more detail. The pattern is divided into four vertical and horizontal sections. However if there were more divisions it would be possible to create a more accurate pattern with smoother curves. The patternmaker has to work with different geometric rules; for example, there are 355° in a rotation because the curvature is spherical (see figure 10). This process is similar to draping a piece of paper (non-stretch material) onto the sphere to create a pattern. The paper pattern also fits the triangle on the pattern well, compared to the other patterns (see figure 11).

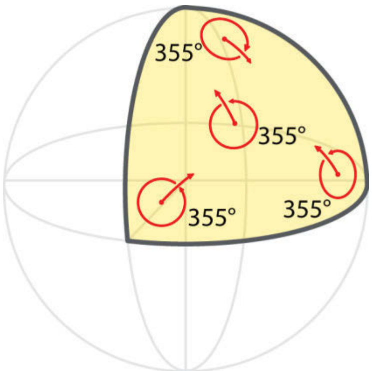


Figure 10: Each point on the sphere with a 5 cm radius has a cone angle of 355°, that is less than 360°.

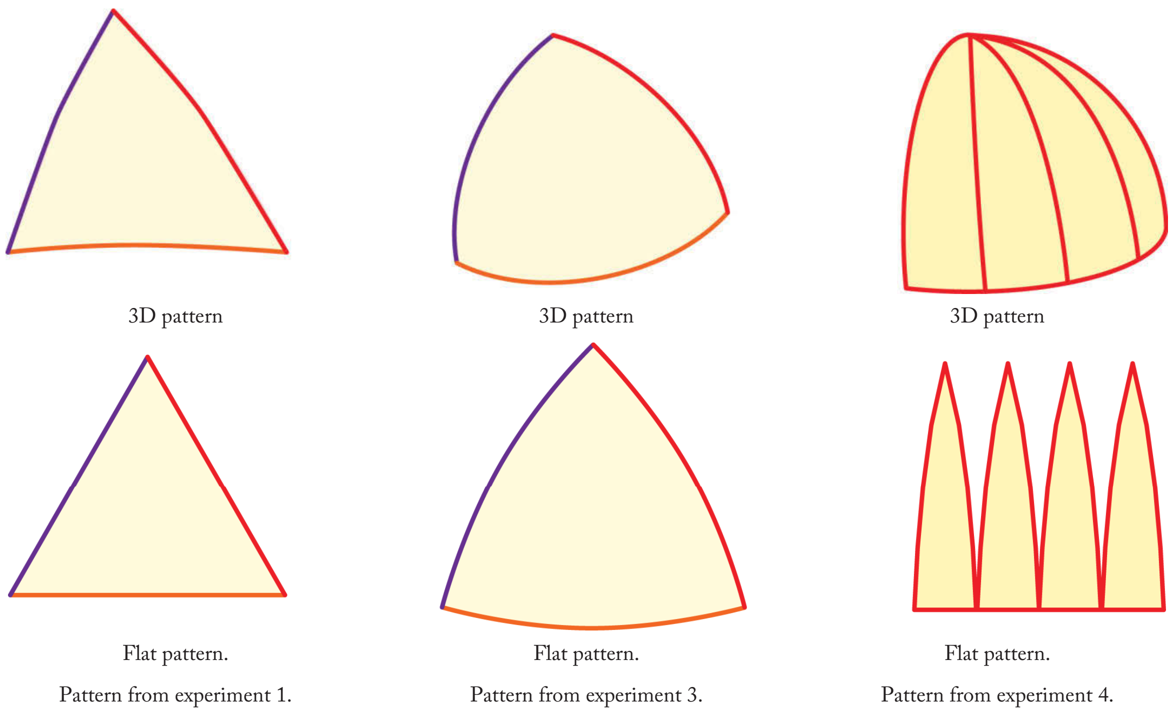


Figure 11: The pattern with linear and angle measurements fits well.

Conclusion

The experiment shows that linear measurements alone do not give enough information to record the shape of a curved surface and translate it into an accurate flat pattern. The addition of angle measurements to the flat patterns shows the limitations of translating direct angle measurements onto a flat pattern. A triangle on a flat surface can only have 180°, whereas a triangle on a sphere can have more than 180°. Treating linear measurements as straight lines on a flat piece of paper is also limited in its ability to record the three-dimensional form of the garment. Using soft wire to record curved edges of the pattern is effective on the edges, but not entirely successful over the whole pattern. The most accurate technique is a combination of angle and linear measurements. These should be measured in a triangular grid over the larger triangle.

14. Re-Evaluating How to Measure the Body

Experiment 48: **Revising draping of a block pattern**

Experiment 49: **Revising Efrat's block pattern**

Experiment 50: **Revising draping a skirt block pattern**

Experiment 51: **Draping any contour**

Aim

This group of experiments uses concepts from Non-Euclidean geometry to re-evaluate traditional patternmaking techniques. The research offers an alternative technique for measuring the body and drafting a block pattern. When measuring the body, both linear and angle measurements are taken to capture the curvature. The measurements form a triangular grid, which prevents them from pivoting and losing accuracy. They in fact give critical angle measurements on bust point using the drape measure, while linear measurements are taken with a tape measure. Using techniques devised for bust point manipulation, it can replace the tip of the cone at bust point with a cone tip that gives the pattern a curved surface. The research applies these techniques to both a skirt block and any contour that creates a three-dimensional surface.

Method

The first experiment demonstrates the importance of using angular measurements when drafting a pattern. These are essential for measuring its curvature. The second experiment re-evaluates a technique devised by the fashion technologist Efrat (1982), whereby the approach treats garments like cones and uses a computer program to calculate linear measurements into cone angles. This alternative takes inspiration from Efrat (1982) but does not use any calculations. It uses the drape measure to measure the dart angle, then divides the rest of the patterns into a series of triangles. Using a combination of linear and angle measurements it creates an accurately fitting block pattern. Further, using techniques developed from bust point manipulation, it is possible to move the location of the bust point around the pattern. The third experiment shows how to generate a skirt block using the same method of linear and angular measurement, and the last test demonstrates how any curved surface can be mapped using a combination of linear and angular measurements.

Analysis

This experimental group implements many of the ideas developed in previous experiments that seek to increase accuracy in measuring curved Non-Euclidean surfaces. The decision to measure linear and angle measurements is critical for recording the curvature of the body. Measuring the body in a pattern deconstructed into a series of triangles makes it easier to record the curvature, and this pattern's rigid formation prevents the measurements from pivoting. The drape measure is also a critical tool that lets patternmakers quickly and accurately take angle measurements. This approach also allows us to re-evaluate traditional techniques of drafting tops and skirts. In fact, it is possible to apply it to any contour pattern.

Experiment 48: Revising Draping of a Block Pattern

Rationale

This experiment tests an alternative method of taking angle measurements off the body to draft flat patterns. Traditionally, fashion patternmakers use a tape measure to take linear measurements off the body. These are used to derive contours and cone angles that determine the body shape. The experiment explores an alternative technique whereby cone angles can be measured directly off the body in order to get more accurate measurements. This also puts less reliance on drafting formulae and linear measurements.

Hypothesis

The research anticipates that it can create an accurately fitting block pattern using a combination of tape measure and drape measure. A key advantage of taking angle measurements off the body is its speed and accuracy. Traditionally, angle measurements and contours have been derived from a series of linear measurements, but if a single linear measurement is inaccurate it affects the accuracy of all measurements. Thereby, direct measurement off the body gives the patternmaker a new way forward.

Experimental Design

The experiment shows in several steps how to use a drape measure to take more accurate measurements off the body. The first part shows how critical measurements such as dart angles on the bust and waist can be measured off the body. The second part draws lines on the surface of the body and breaks these measurements into a series of linear and angle measurements, while the third part demonstrates that by drawing a contoured seam line on the surface of the body the pattern can be flattened into a series of angle measurements and linear measurements.

Procedure

The first iteration shows how the drape measure can be used to measure critical points of the body that shape the pattern, taking measurements off flat, spherical and hyperbolic surfaces.

Part 1:

Model 1: As a control model, a flat piece of material on a flat surface has an angle measurement of 360°.

Model 2: Place a drape measure on the bust point on a mannequin. Use the drape measure to measure the dart angle at that point.

Model 3: Place a drape measure on the waist of a mannequin. Use the drape measure to measure the dart angle at that point.

Part 2:

The second iteration shows how a contoured seam line drawn on the body can be deconstructed into a series of linear and angle measurements.

Model 4: On the torso of the mannequin, draw a seam line from the armhole to the waist of the garment passing over bust point. Deconstruct the line into a series of apex points and tangent points. Take angle measurements at the apex points. Measure the distances between each linear measurement as linear measurements.

Model 5: Cut down the seam line to create a flat contoured pattern.

Model 6: Re-create model 5, this time drawing a line from each apex point to the left edge of the garment. The dart at each apex point should be the same as the cone measurement taken by the drape measure.

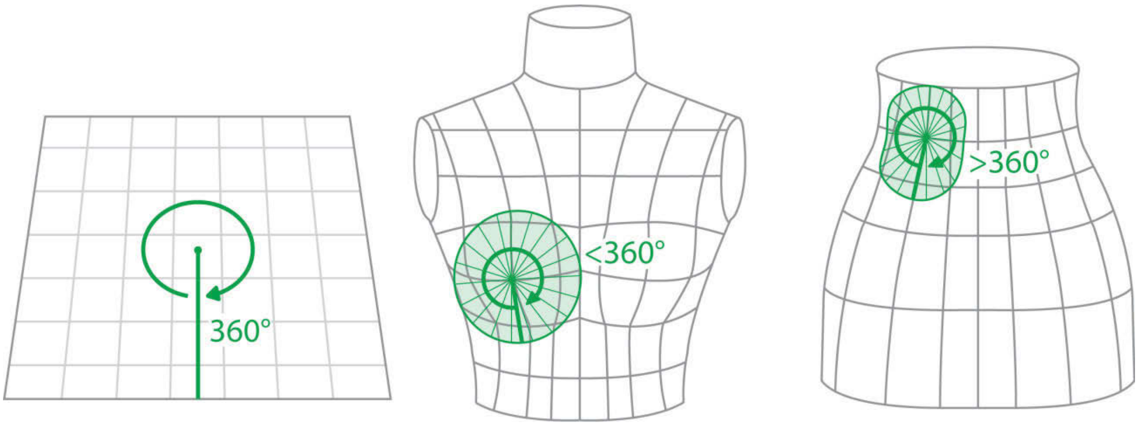
Part 3:

The third iteration shows how common linear measurements off the body can become more accurate with the addition of angle measurements.

Model 7: Start with a mannequin and draw a line from the shoulder that crosses over bust point and runs down the front of the garment. Draw linear measurements at the bust, waist and hip level. Deconstruct the curved lines into a series of straight lines and apex points. This will turn the pattern into a series of linear measurements and angle measurements.

Results

Part 1:



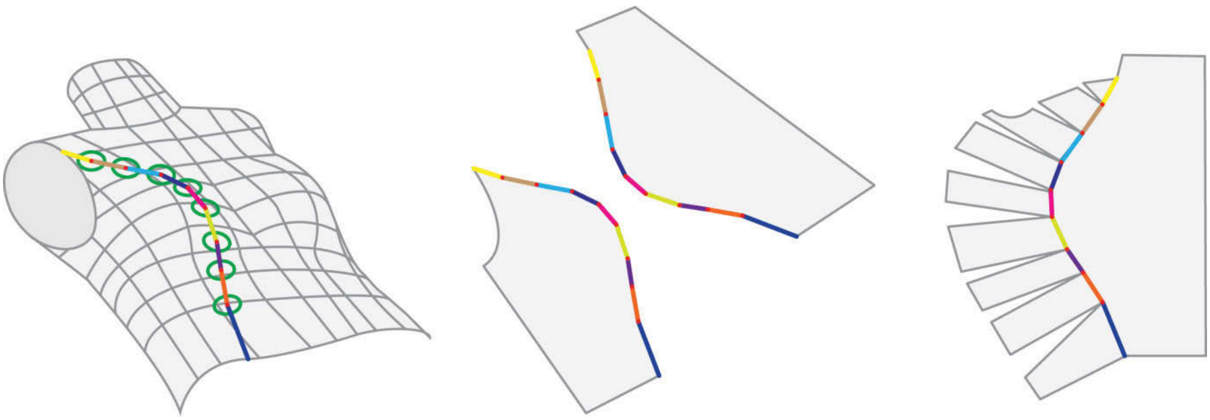
Model 1:
A flat piece of material has
a cone angle of 360°.

Model 2:
The bust has spherical curvature and
a cone angle of less than 360°.

Model 3:
The waist has hyperbolic curvature and
a cone angle of greater than 360°.

Figure 1: The drape measure is able to measure cone angles all over the body.

Part 2:



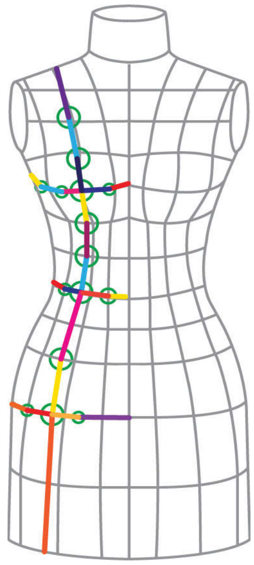
Model 4:
The curvature of the body shown as straight
lines and apex points.

Model 5:
With contour manipulation the curved
pattern can be broken down into a series of
straight lines.

Model 6:
These lines also have dart angles
as their apex points.

Figure 2: A complex curved surface can be broken down into a series of straight lines and dart angles.

Part 3:



Model 7

Figure 3: Using contour manipulation any curved surface can be broken down into a series of straight lines and apex points.

Conclusion

Using a drape measure, it is possible to take angle measurements off the body, measuring critical parts of a pattern such as darts, which determine the curvature of the surface. It can also measure seam lines on a surface as a series of angles, in order to accurately measure a contoured seam line.

Experiment 49: Revising Efrat's Block Pattern

Rationale

This experiment tests a new method of generating a block pattern by taking both linear and angle measurements off the body. Traditional fashion patternmaking techniques take a series of linear measurements off the body and use them to draft a flat pattern of the garment (see figure 1). The fashion technologist Efrat (1982) tried to improve on these techniques. Using the mathematics of conics he devised a computer program to calculate the cone angle of the garment from a series of linear measurements (Efrat 1998, pp. 75 – 87 & 102 – 117). This technique suffered from the difficulty of taking accurate linear measurements that compounded into less accurate angle measurements (Kwong 2004, pp. 208 - 209). The experiment tests a new technique inspired by Efrat's approach (1982) but revised to use a combination of a drape measure and tape measure. The goal is an accurately fitting pattern that lets the patternmaker accurately draft the body without the need for a computer or complicated drafting formulae.

Hypothesis

The research anticipates that it can create an accurately fitting block pattern by using a combination of tape measure and drape measure, matching the accuracy of Efrat's technique (1982). One advantage of the new approach is that the drape measure can quickly and accurately take angle measurements.

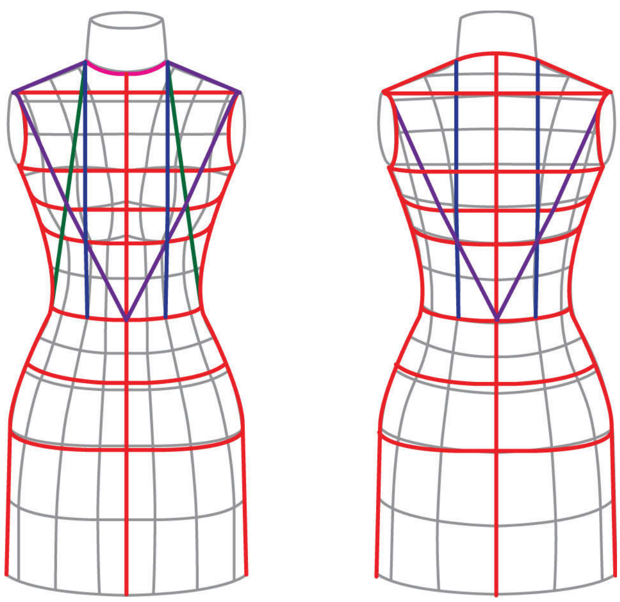


Figure 1: A block garment is usually drafted by taking linear measurements off the body.

Experimental Design

The first part of the experiment will demonstrate how to take measurements off the body and translate these measurements into a flat pattern. The second part demonstrates different techniques of manipulating the tip of the cone at bust point.

Procedure

The experiment consists of two parts.

<u>Part 1</u>:

The process of taking measurements off the mannequin

Step 1: Identify bust point (the fullest part of the bust) on the mannequin.

Step 2: Place the drape measure on bust point and measure the dart angle. Use the drape measure to create the desired cone angle for the block pattern. Pin the drape measure to the measure that holds its cone angle. Attach the drape measure to the mannequin with pins. If draping on the body, hold the drape measure in place using double-sided adhesive tape ("Hollywood tape"). Holding the drape measure in place will form a point of reference for the linear measurements.

Step 3: Define body landmarks on the mannequin, on the centre front, waist, side seam, armhole and neckline (see figure 2). Take linear measurements from bust points to key body landmarks needed to shape the pattern. These measurements are like taking a measurement on a cone that has a centre point at bust point (see figure 3). Once the cone angle is measured, the linear measurements are essentially straight lines on the surface of a cone (see figure 4). When recording linear measurements, use the drape measure to record the angle that the linear measurement points from (see figure 5). This calibrates all linear measurements from the position of bust point. It also helps to mark the locations of body landmarks using pins or stickers.

The number and location of body landmarks can be increased or decreased in order to improve the accuracy of the block pattern. Different body shapes may also need different landmarks to define their shape. For the purpose of this experiment it should create a basic block dart with the minimum number of measurements. Remember to divide the block into a series of triangles so that the measurements are rigid and cannot pivot.

Step 4: Take linear measurements between the different body landmarks.

Transcribing the measurements into a flat pattern

Step 5: Transcribe the angle measurements onto a flat piece of paper. Start at bust point and define the dart angle by subtracting the cone angle from 360°. Mark out the different angles at which the different body landmarks are located.

Step 6: Transcribe the linear measurements onto the pattern. Use the angle measurements to define the direction of each linear measurement.

Step 7: Draw a line to join together the different body landmarks on the pattern. These form the side measurements. Compare these measurements to the side measurements taken off the body. They should be the same length or similar. If they are not, then the pattern has a more complex curvature and needs to add more body landmarks to increase the accuracy. If the side measurements are not similar, return to step 1 and add more body landmarks to increase accuracy.

Step 8: This method of measurement can be applied to the front and back block of the pattern (see figure 8). On the back of the garment, in place of the bust point choose the fullest part of the back. This can be the tip of the shoulder blade, but it all depends on the shape of the body.

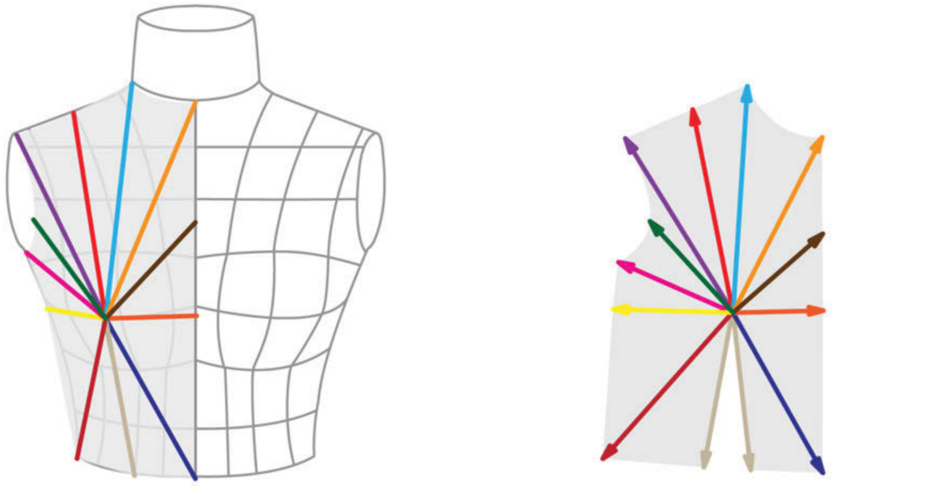
Part 2:

The second iteration shows how to manipulate the tip of the cone at bust point so that it does not have an undesirable pointy shape. Different techniques can be applied to create a curved effect at bust point.

Step 9: When draping the drape measure onto the bust, observe the location at which the cone makes contact with the bust. This forms a circle called the bust contact point. This is the point at which the block pattern makes an undesirable pointy shape. Mark out the bust contact point and draw a circle on the cone to show its location.

Step 10: Once the bust contact point is identified, draw a circle on the cone pattern centred at bust point. The tip of the cone can be cut off to remove the pointy-shaped cone tip.

Step 11: The tip of the cone can be replaced with similar-shaped cone tips that create a curved shape on the tip. The designer has a wide variety of patterns to choose from that will create a curved form at bust point (see figure 12). This iteration demonstrates how taking angle measurements off the body can be used to facilitate techniques that move the tip of the cone around bust point.



The location of body landmarks on the body. The location of body landmarks on a flat pattern.

Figure 2: The locations of body landmarks.

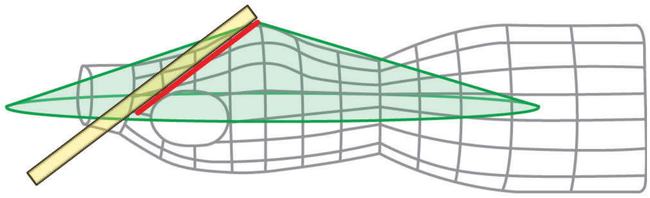


Figure 3: Once the cone angle is measured, the linear measurements taken on the body are essentially straight lines on the surface of a cone. A straight ruler can also be used to record these measurements.

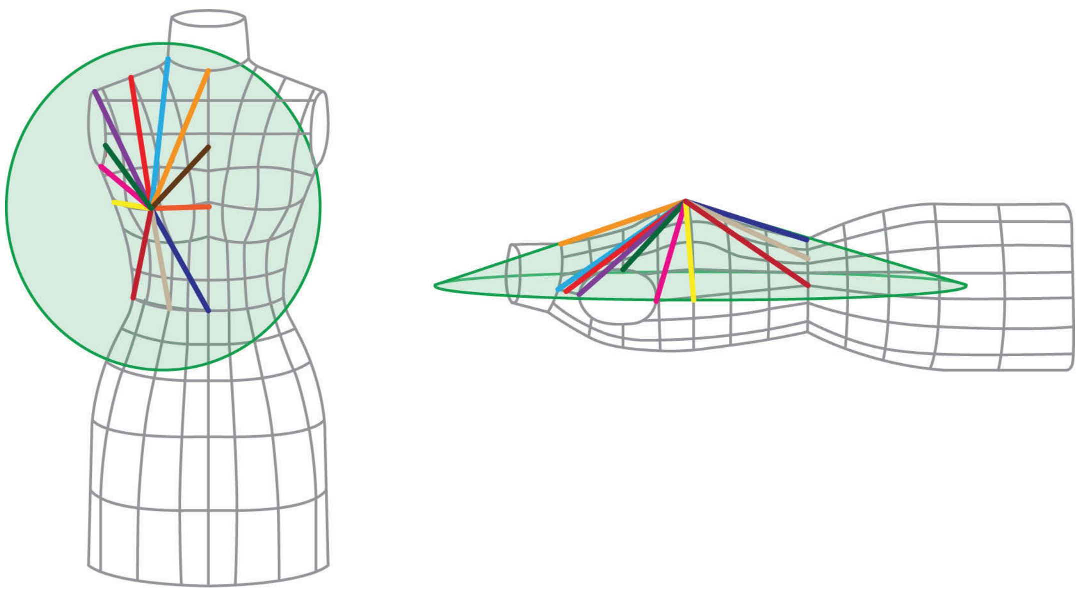


Figure 4: Once the cone angle is known, the linear measurements are effectively straight lines on the surface of a cone.

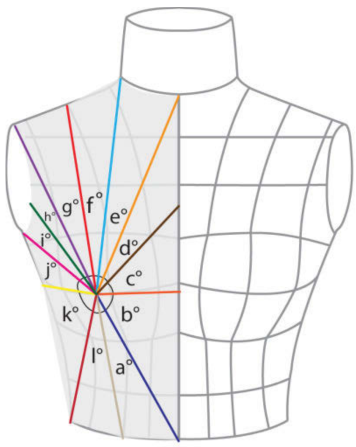
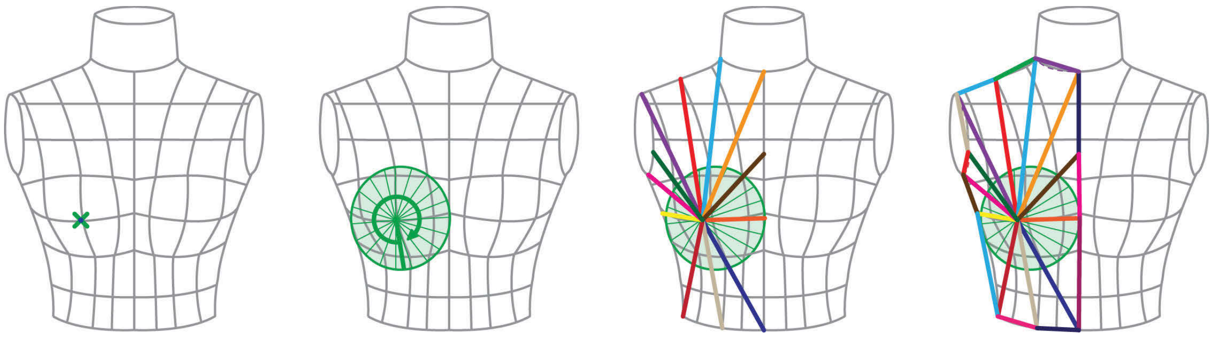


Figure 5: Record the angle measurement of the linear measurement.

Results



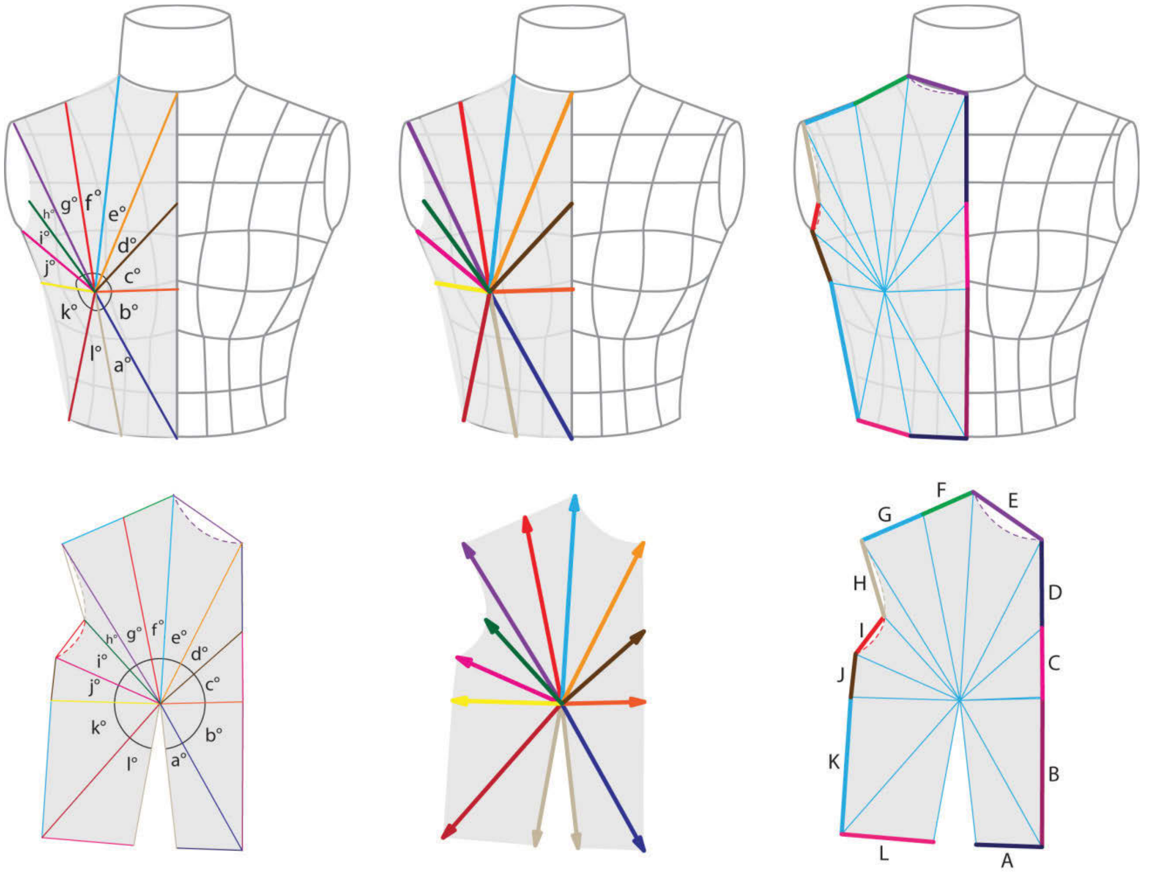
Step 1:
Identify the apex
on bust point.

Step 2:
Measure the cone angle.

Step 3:
Measure linear measurements to
different body landmarks.
Measure the angles between these
linear measurements.

Step 4:
Measure the side
measurements between the
different body landmarks.

Figure 6: Taking measurements off the body.



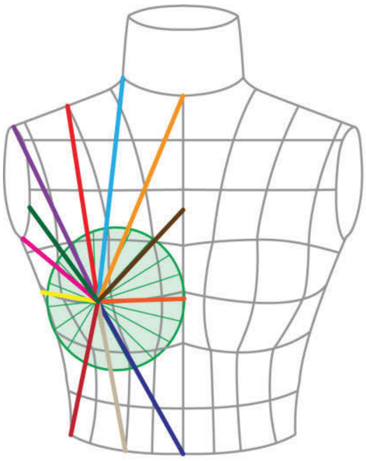
Step 5:
Angle Measurements.
Transcribe the cone angle.
Mark in all the angles between
the body landmarks.

Step 6:
Linear Measurements.
Transcribe the linear measurements
onto the flat pattern.

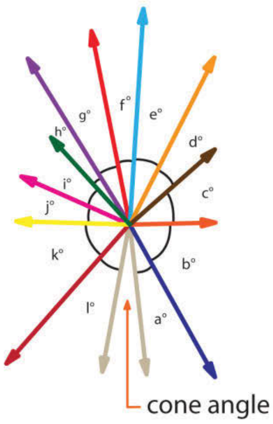
Step 7:
Side Measurements.
Join the lines between the linear
measurements. These measurements should
correspond to the side measurements taken
off the body.

Figure 7: Transcribing measurements into a flat pattern.

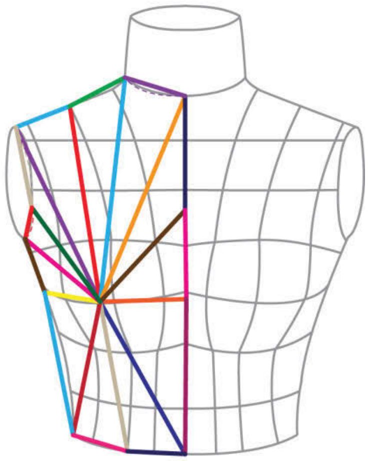
Front and back of the garment.



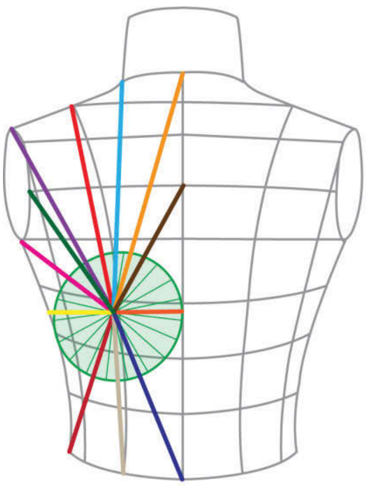
Front of the garment.



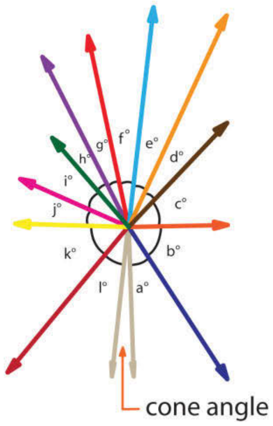
Record the cone angle, linear measurements and the angles between the linear measurements.



Record the side measurements between the body landmarks.

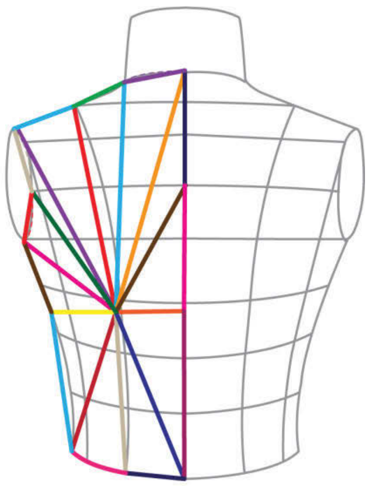


Back of the garment.



Record the cone angle, linear measurements and the angles between the linear measurements.

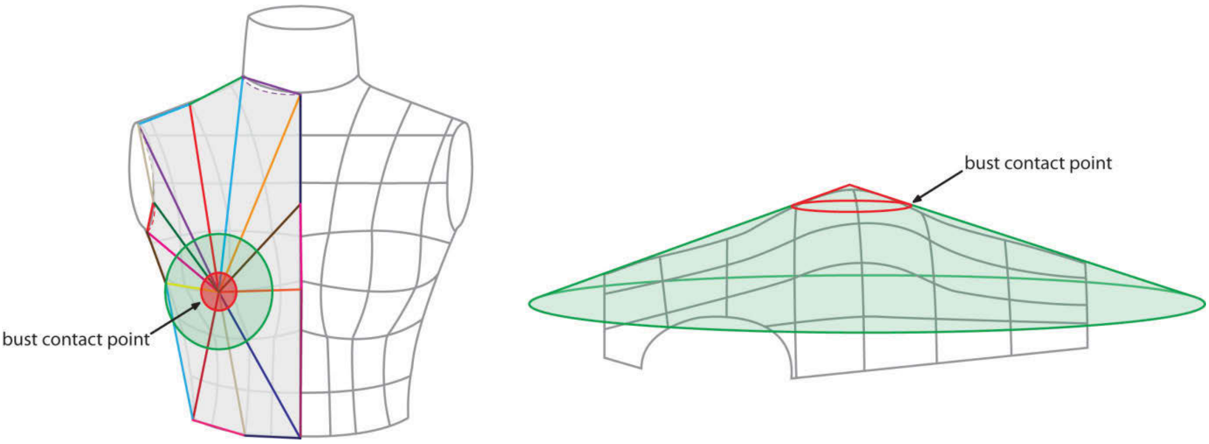
Step 8



Record the side measurements between the body landmarks.

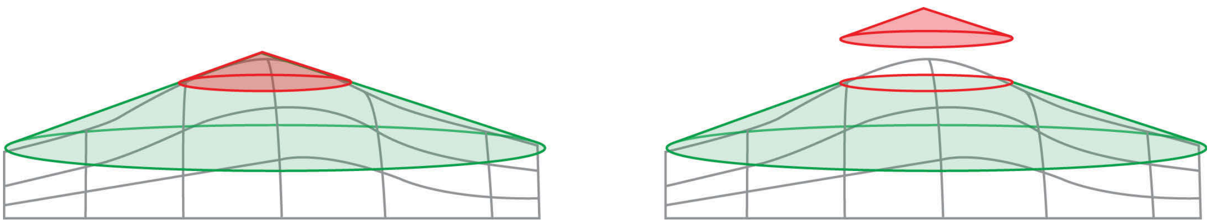
Figure 8: To create an accurate basic block pattern, first measure the cone angle. Then measure linear measurements to the different body landmarks. Next, measure the angles between the linear measurements. Finally, take the side measurements between the body landmarks.

Part 2:



Step 9

Figure 9: The bust contact point is the point at the edge of where the garment stops making contact with the body.

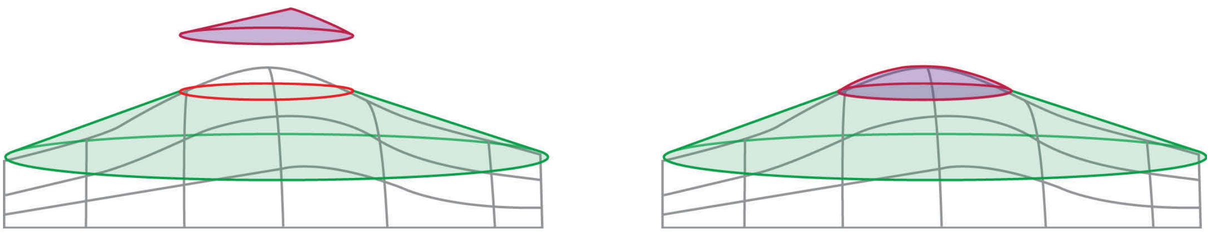


Bust contact point identified.

Cone cut off the tip of the bust contact point.

Step 10

Figure 10: The tip of the bust can be cut off at bust contact point.



A new cone tip with the apex moved away from bust point.

This creates a curved shape when mounted on the bust.

Step 11

Figure 11: The pointy tip of the cone can be replaced with one that can contour to the curved shape of bust point.

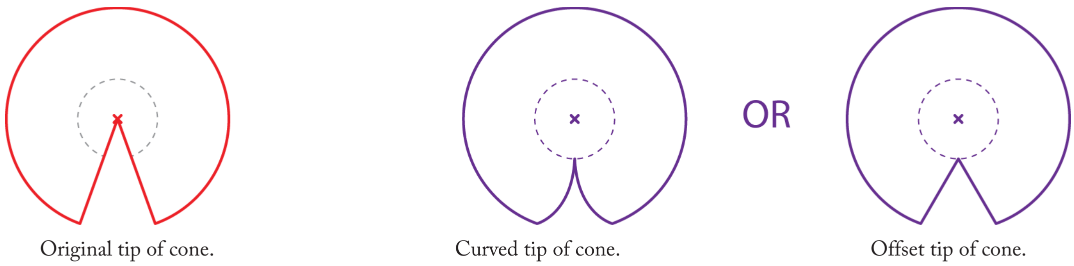


Figure 12: The tip of the cone at bust point can be replaced with different cones which can curve to the contours of the bust.

Conclusion

The experiment demonstrates a new technique that uses a combination of linear and angle measurements to draft an accurate flat pattern. By treating the garment block as a cone, it can simplify the patternmaking process. The technique can be applied by using a tape measure and a drape measure, but it is also conceivable that the technique could be automated into a three-dimensional scanner and computer program.

Experiment 50: Revising Draping a Skirt Block Pattern

Rationale

This experiment tests a new method for generating a block pattern for a skirt, by taking both linear and angle measurements off the body. Traditional fashion patternmaking techniques take a series of linear body measurements and use them to draft a flat pattern of the garment. The research tests an approach that uses both linear and angle measurements to increase the accuracy of the pattern.

Hypothesis

The research anticipates the creation of an accurately-fitting skirt block pattern by using a combination of the tape measure and drape measure.

Experimental Design

The experiment accurately drafts a pattern for the front and back of the garment using a combination of tape and drape measure, whereby it takes a series of linear and angle measurements off the body and transcribes them into a flat pattern.

Procedure

It drafts the skirt's front and back block pattern.

The Front

Step 1: Identify the fullest part of the front of the skirt. This is usually located on the waist of the mannequin. This is to be the location of the dart. The dart can also be re-positioned to accommodate any dart location a designer may want. Use the drape measure to find the cone angle of the dart.

Step 2: Identify body landmarks on the pattern that define its shape. These include the waist, side and centre front (see figure 1).

Step 3: Take linear measurements from the dart apex to the body landmarks. Record the angle measurements between each linear measurement. Measure the linear measurements between each of the body landmarks.

Step 4: Transcribe these measurements onto a flat piece of paper. First draft the apex point and the cone angle. Then draw each of the linear measurements from the apex point. Finally, draw the side measurements between the different body landmarks. Use this combination of angle measurements, linear measurements and side measurements to check the accuracy of the pattern.

The Back

Step 5: Identify the fullest part of the back of the skirt. The dart can also be re-positioned to accommodate any dart location a designer may want. Use the drape measure to find the cone angle of the dart.

Step 6: Identify body landmarks on the pattern that define the shape of the pattern. These include the waist, side and centre front (see figure 1).

Step 7: Take linear measurements from the dart apex to the body landmarks. Record the angle measurements between each linear measurement. Measure the linear measurements between each of the body landmarks.

Step 8: Transcribe these measurements onto a flat piece of paper. First draft the apex point and the cone angle. Then draw each of the linear measurements from the apex point. Finally draw the side measurements between the different body landmarks. Use this combination of angle measurements, linear measurements and side measurements to check the accuracy of the pattern.

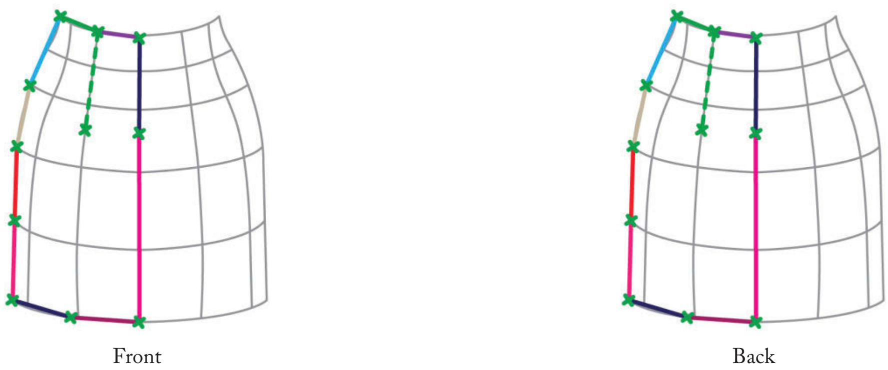
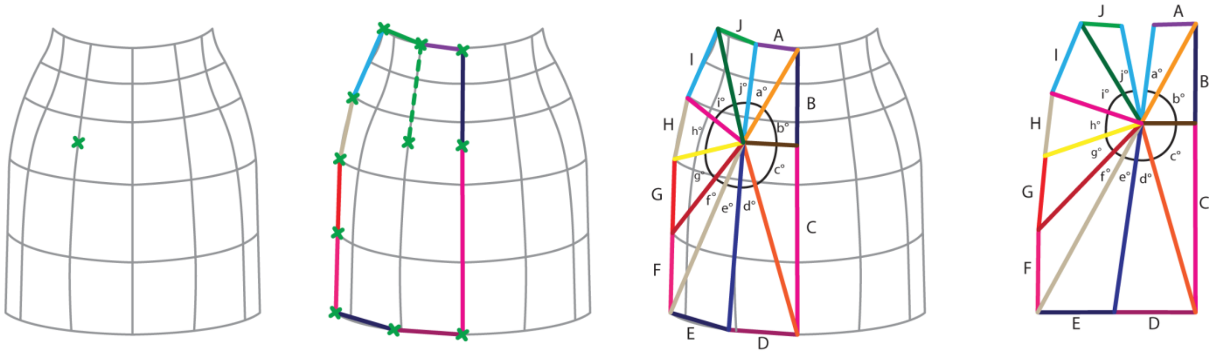


Figure 1: Locations of body landmarks on the skirt block.

Results

Front of the garment:



Step 1:
Identify the apex point.
Measure cone angle.

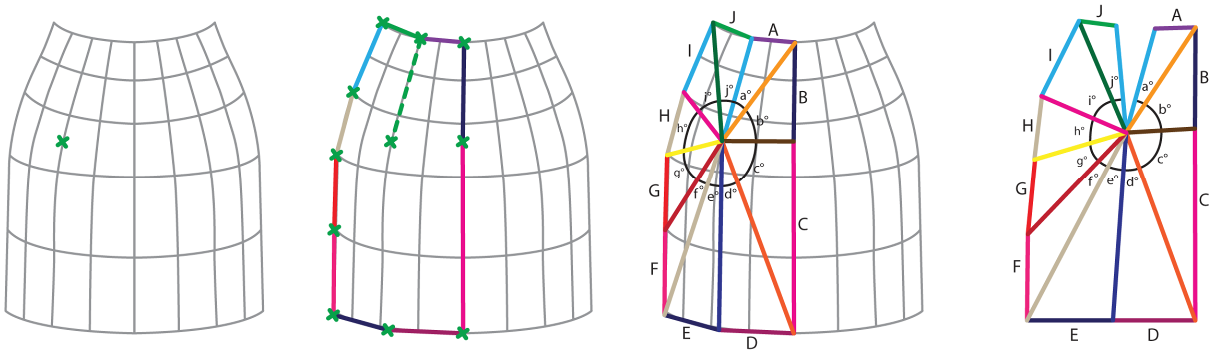
Step 2:
Identify dart location.
Identify body landmarks.

Step 3:
Take linear measurements from the apex point to body landmarks.
Take angle measurements between linear measurements.
Measure the side angles between body landmarks.

Step 4:
Transcribe the cone angle, linear measurements, angle measurements and side measurements into a flat pattern.

Figure 2: A summary of how to transcribe measurements off the body into a basic block for the front of the garment.

Back of the garment:



Step 5:
Identify the apex point.
Measure cone angle.

Step 6:
Identify dart location.
Identify body landmarks.

Step 7:
Take linear measurements from apex point to body landmarks.
Take angle measurements between linear measurements.
Measure the side angles between body landmarks.

Step 8:
Transcribe the cone angle, linear measurements, angle measurements and side measurements into a flat pattern.

Figure 3: A summary of how to transcribe measurements off the body into a basic block for the back of the garment.

Conclusion

The experiment offers a new technique that uses a combination of linear and angle measurements to draft an accurate skirt block pattern. By treating the garment block as a cone it is possible to simplify the patternmaking process. The technique can be applied by using a tape measure and a drape measure, but it is conceivable that the technique can be automated, using a three-dimensional scanner and computer program.

Experiment 51: Draping Any Contour

Rationale

This experiment shows that with the use of a drape measure it is possible to measure the different cone angles of apex points on a contoured seam. In contour manipulation, any contoured line can be deconstructed into a series of straight lines with darts and gussets. Using a drape measure it can measure the cone angle on different points of a curved seam directly off the body. This is a way of measuring contours off the body and accurately recording them as flat patterns.

Hypothesis

The research anticipates using a drape measure to measure the cone angles at different apex points on a contoured seam line will allow the patternmaker to take accurate measurements of parts of a contour.

Experimental Design

The drape measure can measure the cone angle at any point on the body (see figure 1). In contour manipulation any contour can be deconstructed into a series of darts and gussets (see figure 2). In this experiment, it measures a contoured seam line off the body by deconstructing it into a series of straight lines and apex points. It then measures the cone angles at each apex, using the drape measure.

Procedure

Part 1:

The first iteration takes a single contoured seam line and uses a rule and a drape measure to record a flat pattern.

Model 1: Mark out a contoured seam line on the bust of the mannequin. Use a straight rule to deconstruct the curve into a series of straight lines and apex points. Record these linear measurements.

Model 2: Measure the cone angles at each of the angle points.

Model 3: The contoured seam line can be recorded as a series of straight lines and angle measurements.

Part 2:

The second iteration takes two curved contour lines that cross over each other and uses the drape measure to accurately take its measurements off the body.

Model 4: Mark out two contour lines that cross over each other at bust point.

Model 5: Use the straight edge of a rule to deconstruct each of the curved into a series of straight lines and apex points. Record the measurements of the straight lines.

Model 6: Measure the angles at each of the apex points.

Model 7: Translate the linear and angle measurements of the contour onto a flat piece of paper. This creates a new paper pattern.

Model 8: To further improve measurement accuracy, the patternmaker can draw up a grid of triangles between the different apex points in order to triangulate the pattern. This creates a rigid pattern that cannot pivot and allows more accuracy. Here, there is a plethora of measurements to take, so the patternmaker can choose the measurements that are most important for the task at hand.

Results

Part 1:

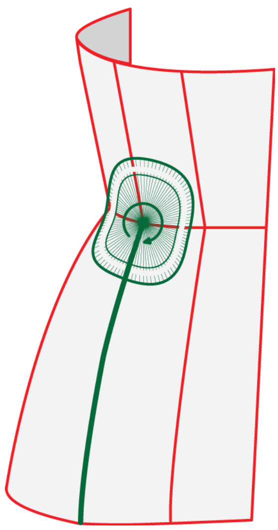
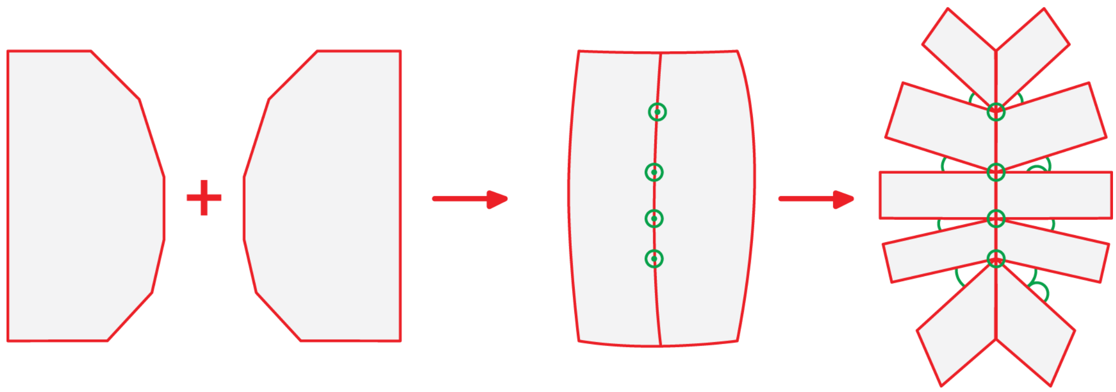


Figure 1: Measuring an apex point on the waist creates a point with more than 360°, and is hyperbolic in shape.

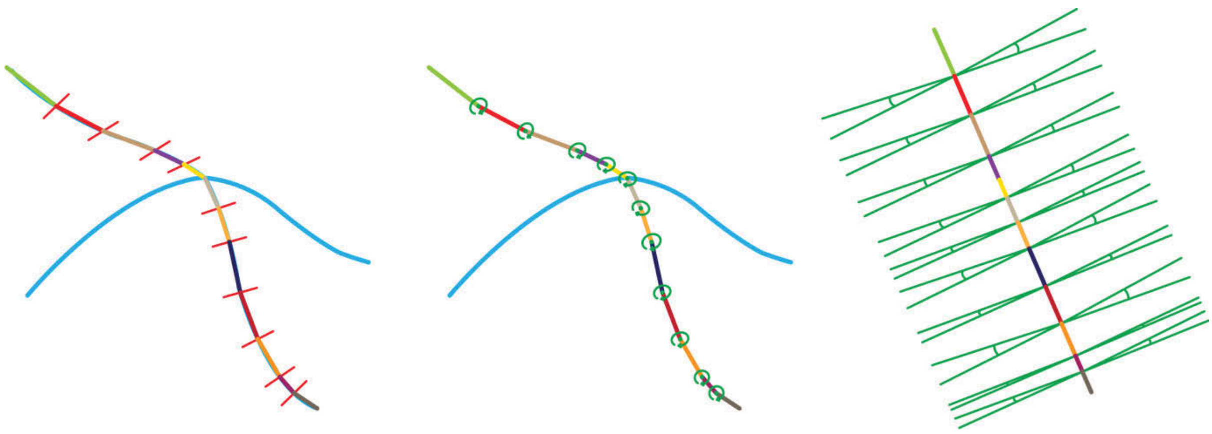


A contoured seam line as a flat pattern.

A contoured seam line in three dimensions.

A contoured seam line deconstructed using contour manipulation into a series of linear measurements and apex points.

Figure 2: A contoured seam line can be deconstructed into a series of linear measurements and dart angles.



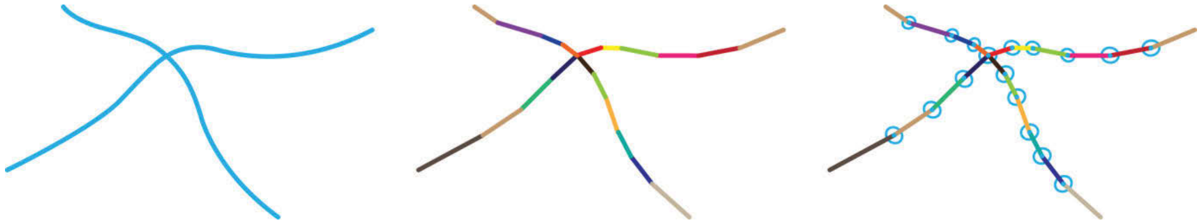
Model 1:
A contoured seam line deconstructed into a series of tangent lines.

Model 2:
The cone angle at each apex point can be recorded.

Model 3:
Using contour manipulation, the curve can be deconstructed into a series of linear measurements and cone angles.

Figure 3: Contoured seam lines can be measured on the body using a tape measure and drape measure to create accurate flat patterns.

Part 2:

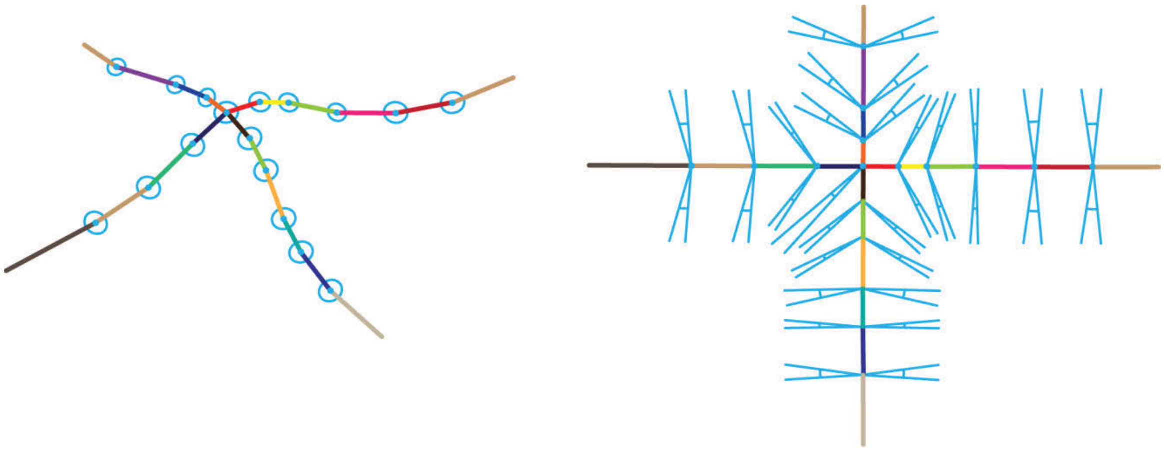


Model 4:
A curved surface can be defined as a set of curves.

Model 5:
The curves can be deconstructed into a series of tangent lines and apex points.

Model 6:
This can be recorded as a series of cone angles and linear measurements.

Figure 4: A curved surface can be defined as a set of curves. These curves can then be measured as a series of straight lines and cone angles.

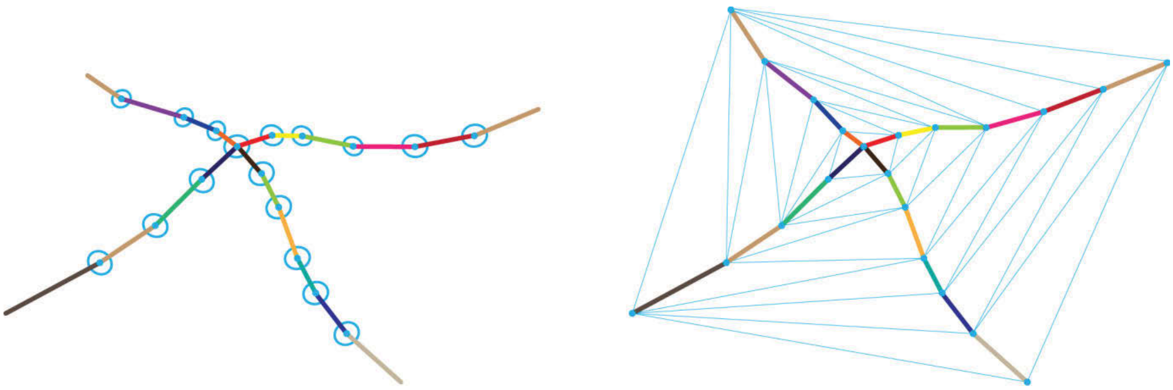


A curve recorded as a series of cone angles and linear measurements.

The same curve as a flat pattern.

Model 7

Figure 5: A curve recorded as linear measurements and cone angles can be flattened into an accurate pattern.



Model 8

Figure 6: Triangulating the apex points of a garment makes it easier to keep track of the apex points. Multiple measurements can be taken between apex points to ensure their accuracy.

Conclusion

The experiment shows that it is possible to measure cone angles directly off the body using a drape measure. This lets the patternmaker measure the cone angles on a contoured seam line in order to record its pattern. For more complex patterns, multiple seam lines cross over each other and a drape measure can be used to measure the cone angles at critical apexes that shape the garment. This gives patternmakers a direct way of measuring the contours using the drape measure. Some of these techniques may seem invasive in that they directly measure off the body, or else there may seem like a lot of measurements to take. But the measurements can be adjusted to the accuracy required of the pattern. It is quite conceivable that the underlying principles of this technique can be applied to turning three-dimensional scans into flat patterns.

15. Mapping Body Movement Using Flat Patterns

Experiment 52: **Recording body movement as flat patterns**

Experiment 53: **Learning from movement**

Experiment 54: **Mapping bend joints**

Experiment 55: **Mapping rotational joints**

Experiment 56: **Mapping the hip joint**

Experiment 57: **Mapping the shoulder shrug**

Experiment 58: **Mapping the deltoid**

Experiment 59: **Sitting down is complex**

Experiment 60: **A summary of the range of motion**

Aim

This group of nine experiments maps the body as it changes shape over time, by recording movement as a series of flat patterns. Traditionally, garments are constructed as a single static form and rely on the stretch of the fabric to accommodate movement. In these experiments the shape of the human body is mapped in multiple positions over time. In place of a single static pattern it creates a sequence of distinctly-shaped ones. With contour manipulation, the structure and function of these can be analysed. Patternmakers will be able to observe, record and understand which parts of the pattern change shape the most over time, and how these alter their geometry.

Method

These experiments map the movement of the human body by recording its shape as a series of patterns. The first investigates how simple motions such as raising the shoulders, bending the arms or sitting down can dramatically change the garment's shape. The second shows that body movement can become overwhelmingly complex, seeking to simplify complex movement into a simpler series.

The third and fourth experiments map the common joints that occur on the body, namely the bend joint and rotational joint. Since certain parts of the body exhibit a complex range of movement, the fifth, sixth and seventh experiments map the range of motion created by the hip joint, shoulder shrug and deltoid. The eighth experiment examines in detail the complex changes created by sitting down. The final experiment surveys the entire range of body movement.

Analysis

The experiments seek to simplify complex body movement in time into a series of simpler movements. Recording each shape as a three-dimensional pattern makes it possible to flatten the pattern and analyse shape using contour manipulation. Seemingly simple movements such as sitting require many diverse joints and muscles to move, dramatically changing the pattern shape. Commonly-used joints such as bend joints for example, change geometrically from spherical to Euclidean to hyperbolic. The net result is a better way to record and analyse structures that change shape over time.

Experiment 52: Recording Body Movement as Flat Patterns

Rationale

This experiment observes how movement changes the shape of the body over time, and how this can be recorded as a flat pattern. An initial goal in developing contour manipulation was to create a patternmaking technique that could accurately map the body shape as it changes over time. This technique now makes it possible to record the body in different poses and map each of them.

Hypothesis

The research anticipates that it is possible to record the shape of the body in different positions and observe how they change over time.

Experimental Design

The research observes how body movement changes the shape of patterns in time. At this stage they amount to rough observations of different joints and movements. If possible, they are mapped as flat patterns. In making conventional patterns the body is posed in a standing position, but here the body is recorded as a sequence of poses rather than a single static shape.

Procedure

The experiment consists of four parts.

Part 1:

The first part explores how the shape of the shoulder joint changes when the arms are moved around the body. Find a person to model, and draw them with their arms next to their body.

Make a rough sketch of the shape of the arms in different positions. Raise the arms from a standing position to above the head. Then, try to map how the shape of the shoulder changes over time.

Diagram 1: Take a series of sketches of a model with their arms posed in different positions. Superimpose all the drawings on top of each other.

Pose a model with their arms by their side. Sketch the outline of their arms in black.

Pose the model with their arms in front of them. Sketch the outline in pink.

Pose the model with their arms behind their back. Sketch the outline in green.

Pose the model with their arms extended at 90° to the body.

Pose the model with their arms raised above their head.

Diagram 2: Make sketches of the left half of the body to observe how moving the arm changes its shape. This time, include the position of the shoulder joint as a cross mark in the diagram.

Pose a model with their arms by their side. Sketch the outline of their arms in light blue.

Pose the model with their arms extended at 90° to the body. Sketch the outline of their arms in blue.

Pose the model with their arms extended at 120° to the body. Sketch the outline of their arms in green.

Pose the model with their arms raised above their head. Sketch the outline of their arms in pink.

Diagram 3: Sketch the approximate shape of the arm as the shoulder is raised in three-dimensions and as flat patterns.

Part 2:

The second iteration explores how the pattern changes when the wearer bends their elbow. Sketch out different shapes of the sleeve, then using contour manipulation sketch the shape of the derived patterns.

Diagram 4: Observe the shape of the arm as it bends. Sketch the shape of the garment in different positions. Sketch the arm when it is straight. Use contour manipulation to create an approximate flat pattern of the three-dimensional shape.

Sketch the arm when it is bent at 90°. Use contour manipulation to create an approximate flat pattern of the three-dimensional shape.

Sketch the arm when it is bent as far as possible. Use contour manipulation to create an approximate flat pattern of the three-dimensional shape.

Compare the patterns created by these different poses.

Part 3:

The third iteration compares the shape of the garment with a woman in standing position and one in sitting position. It analyses the garment as two distinct patterns and compares the two positions. It references skirts, designed for use in a sitting position (figure 5). They are taken from garments worn by people with disabilities who spend long periods in wheelchairs.

Diagram 5: Observe a female model wearing a dress block in a standing position. Draw an illustration of the model from the side and front view.

Diagram 6: Observe a female model wearing a dress block in a sitting position. Draw an illustration of the model from the side and front view.

Compare the three-dimensional shapes of these different positions.

Part 4:

The final iteration explores how the three-dimensional shape of a garment changes over time with movement. It takes a sequence of images recorded of a woman walking, then draw an illustration of a garment on top to show the different three-dimensional shapes a garment makes when a person walks.

Diagram 7: Record a series of images of a model walking. Each of these images shows the body shape in a different position.

Diagram 8: Draw an illustration of the shape of a shirt and a pant on each garment.

Observe the different three-dimensional shapes that are created when the body walks.

Results

Part 1:

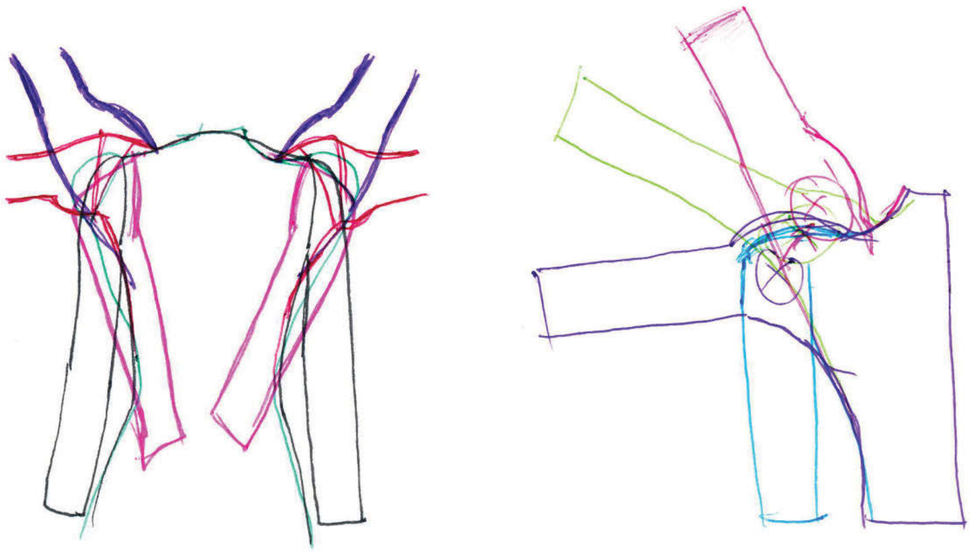


Diagram 1 Diagram 2

Figure 1: A sketch of the contour of the arms and shoulders in motion.

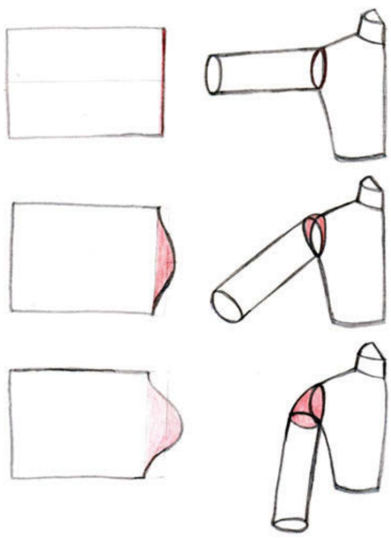


Diagram 3

Figure 2: A sketch of the flat patterns created by the elbow joint in motion.

Part 2:

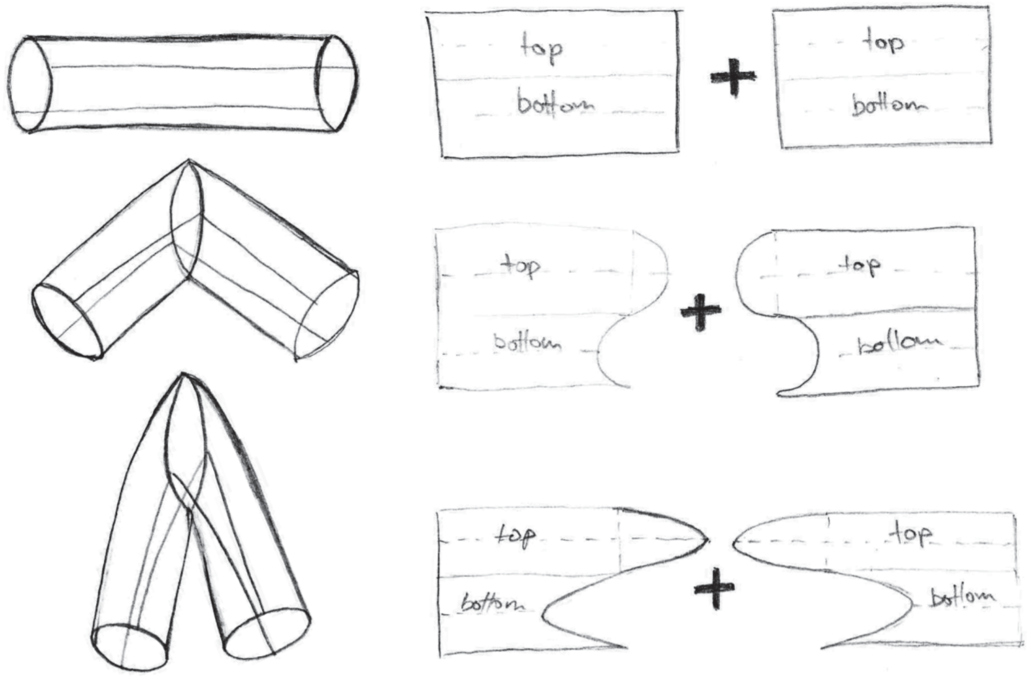


Diagram 4

Figure 3: A sketch of the flat patterns created by the arms and shoulders in motion.

Part 3:

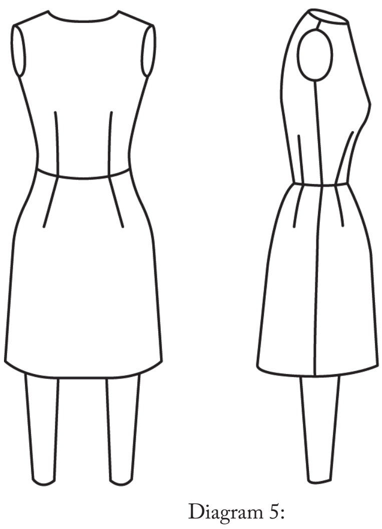


Diagram 5:

A skirt constructed for someone in a standing pose.

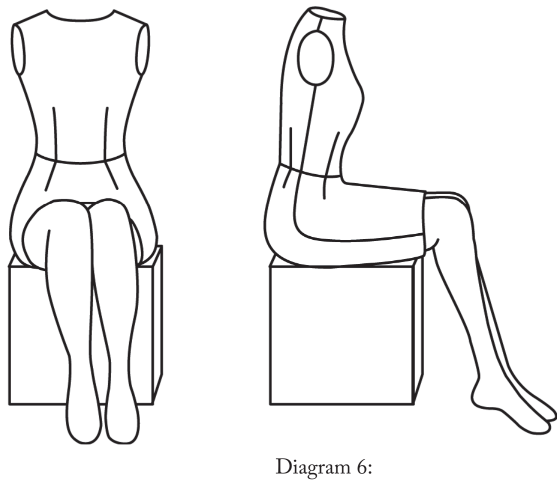


Diagram 6:

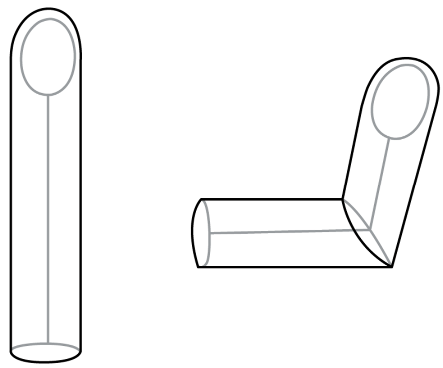
A person wearing a skirt in a sitting pose.

Figure 4: Compare the shape of a garment designed to fit a person in standing position with a person in sitting position.

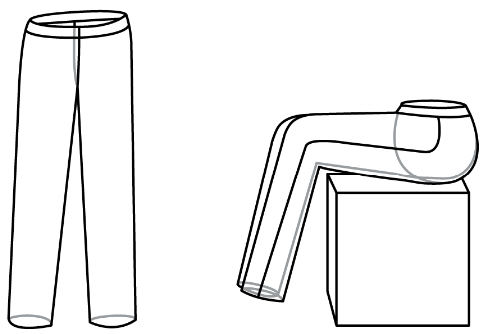
(A) Skirt designed for a woman in a wheelchair shown from the side; the skirt takes a contoured "seated" configuration; (B) the same wheelchair skirt on upright figure; extra length needed in the back for the seated position bunches unattractively on the upright figure.

Figure 5: A skirt designed for a woman who confined to a wheelchair for long durations has a different shape to a conventional skirt (Watkins 1995, p. 243).

It is observed that garments made to fit people in a standing position have very different shapes to those designed to fit in a sitting position. Examples of the latter are people with disabilities who use wheelchairs for long durations.



A sleeve when the wearer is standing straight, compared to a sleeve with a bent elbow.



Trousers when wearer is standing straight, compared to a sitting position.

Figure 6: Patterns are built to fit bodies that are standing straight instead of sitting.

It is noted that both bending the arms and bending the knees creates a similar-shaped bend joint. The arm and leg both transform from a cylindrical tube into an "L" shaped bend.

Part 4:

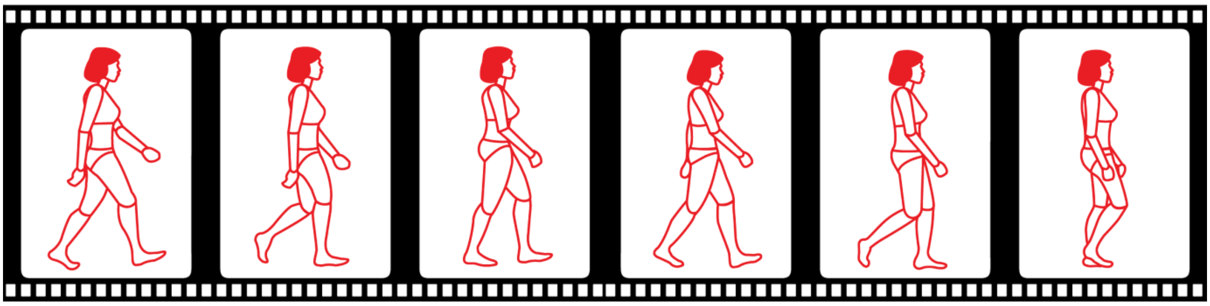


Diagram 7: The human body in motion captured as a series of images.

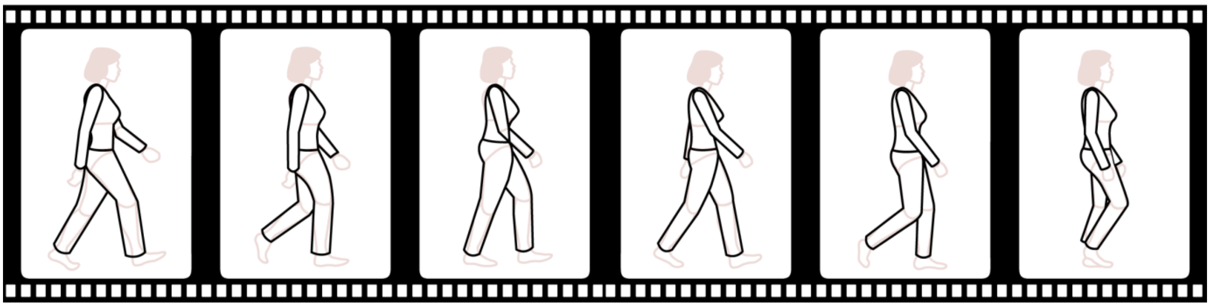


Diagram 8: The human body in motion captured as a series of images.

Figure 7: The garment as a sequence of patterns.

It is observed that each pose makes a unique shape. As the wearer walks, the arms and legs of the patterns alternate between straight tubes and bend joints.

Conclusion

The experiment shows that body movement creates a series of unique three-dimensional shapes. These can be mapped as a series of flat patterns. Conventional techniques create a flat pattern that forms the average of this range of motion. However, with contour manipulation it is now possible to map each individual pose as an accurate three-dimensional pattern.

Experiment 53: Learning from Movement

Rationale and Hypothesis

This experiment distils the complex array of human motion into a set of simpler movements that can be easily analysed by patternmakers. Such an analytical task can be overwhelmingly complex for them. Thereby, the experiment seeks to simplify movement into transformations that affect pattern shape, simplifying motion into joints.

Experimental Design

The experiment makes observations of motion by analysing images from books on movement (see figure 1). These images are deconstructed and assessed (from a patternmaker's point of view) to see how they change the pattern shape.

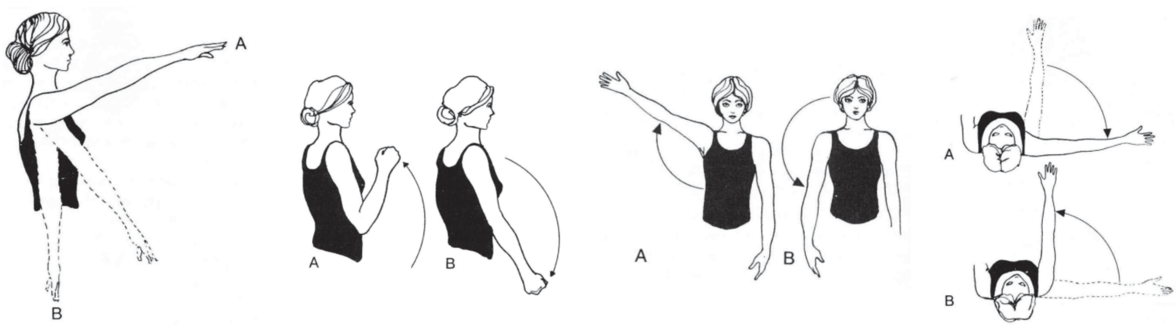


Diagram 1: "(A) Flexion of the arm; (B) Extension of the arm." (Watkins 1995, p. 222).

Diagram 2: "(A) flexion of the elbow. (B) extension of the elbow." (Watkins 1995, p. 222).

Diagram 3: "(A) abduction of the arm. (B) adduction of the arm" (Watkins 1995, p. 222).

Diagram 4: "(A) horizontal abduction of the arm; (B) horizontal adduction of the arm." (Watkins 1995, p. 223).

Figure 1: A summary of the range of movement created by the arms (Watkins 1995, pp. 222 - 223).

Procedure

The experiment consists of two parts.

Set 1:

Model 1: Draw the side view of a mannequin wearing a sleeve pattern on the arm. Position the arm so that it is by the side of the body. Draw a second pattern with the arm bent 90°. Observe the changes to the garment pattern.

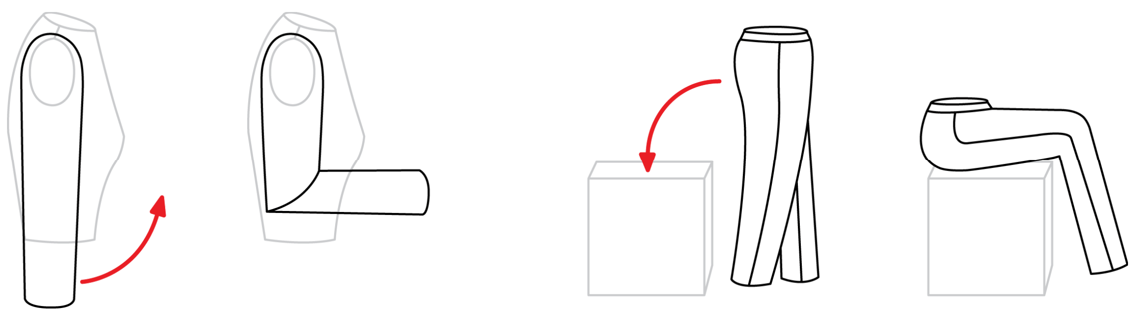
Model 2: Draw the side of a model standing straight and wearing trousers. Draw a second pattern with the model sitting down. Observe the changes to the garment pattern.

Model 3: Draw the front view of a model wearing a shirt with their arms by their sides. Draw a second image of the model on top of the diagram with their arm raised.

Model 4: Draw the side of a model standing straight and wearing trousers, focusing on the hip area. Draw a second pattern of the model with their leg raised. Observe the changes to the garment pattern.

Model 5: Draw the side of a model standing straight (in blue). Draw a second pattern with the model bending over at 45° (in red) and at 90° (in black). Observe the changes to the garment pattern.

<u>Results</u>



Model 1:
Elbow Joint.

Model 2:
Knee Joint.

Figure 2: Bend or hinge joints at the elbow and at the knee.

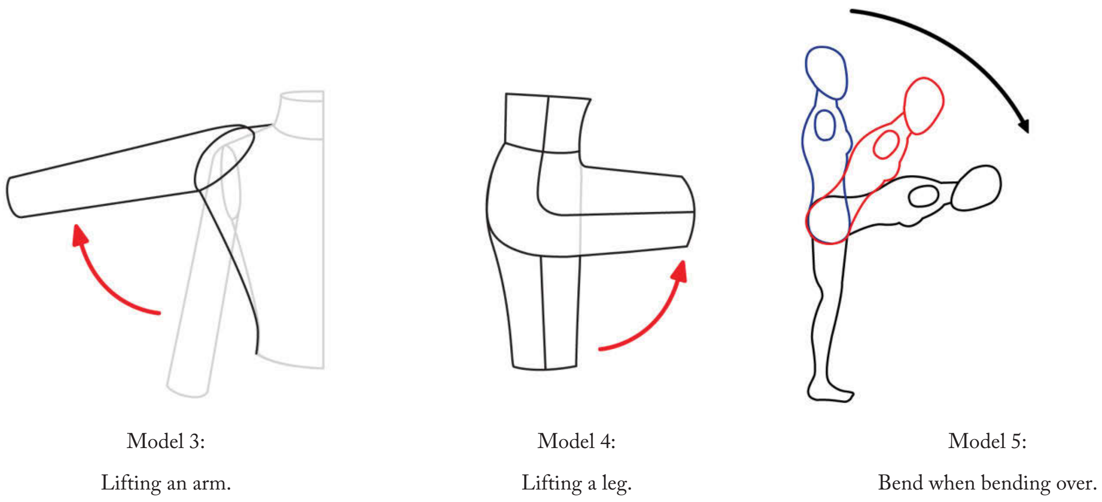


Figure 3: A bend joint is created by a wide range of body movements.

Observations

Some of the movements (including bending the arm and knee) create a bend joint, where a cylindrical tube of fabric is bent into an "L" or "V" shape. Other moves such as lifting the arm, leg or bending over, rotate around a single point. These are rotational joints. These may be anatomically different, but the patterns created by bend and rotational joints have similarities in that both transform the pattern from a straight tube into an "L" or "V" shape.

Conclusion

The complex range of human motion can be distilled into a range of simpler movements. Common shapes created by patterns involve a bending or rotating joint. Both of these change the pattern's three-dimensional form and geometry.

Experiment 54: Mapping Bend Joints

Rationale

This experiment observes how the flat pattern of a sleeve changes shape when the wearer bends the elbow. Patternmakers are familiar with making a pattern to fit a single static shape. There have been few attempts to map the moving shape of the body as a series of flat patterns. Understanding how movement affects the body gives patternmakers new insights on body fit.

Hypothesis

The research anticipates that the flat pattern should change shape over time, from a flat Euclidean shape to a more curved Non-Euclidean shape.

Experimental Design

The experiment maps the garment pattern as it changes in time according to body movement. It analyses the body as a sequence of positions. It records each as a three-dimensional form then flattens it into a flat pattern, following which the research makes observations.

Procedure

To capture the shape of the body as it moves, drape sleeve patterns over a mannequin with arms bent at different angles (refer to figure 1). These patterns are recorded as flat and three-dimensional patterns (refer to figure 1).

Model 1: Start with a mannequin with an arm attached to it. Drape a sleeve pattern onto the arm. Record the three-dimensional shape of the sleeve pattern and flat pattern.

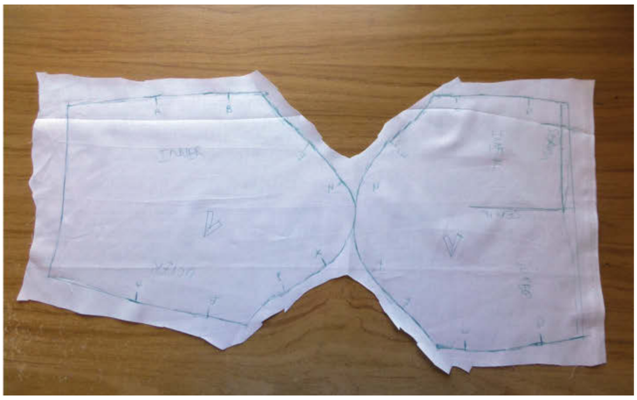
Model 2: Replace the arm on the mannequin with one with arm bent at 130°. Drape a sleeve pattern onto the arm and record its patterns.

Model 3: Replace the arm on the mannequin with one with arm bent at 90°. Drape a sleeve pattern onto the arm and record its patterns.

Model 4: Replace the arm on the mannequin with one with arm bent at 45°. Drape a sleeve pattern onto the arm and record its patterns.

Compare these patterns and make observations on how the flat patterns have changed in time.

Pattern draped on an arm shape in a bended position.



The flat pattern of the pattern draped on the arm.

Figure 1: A pattern draped on the arm in different positions.

Results

Part 1:

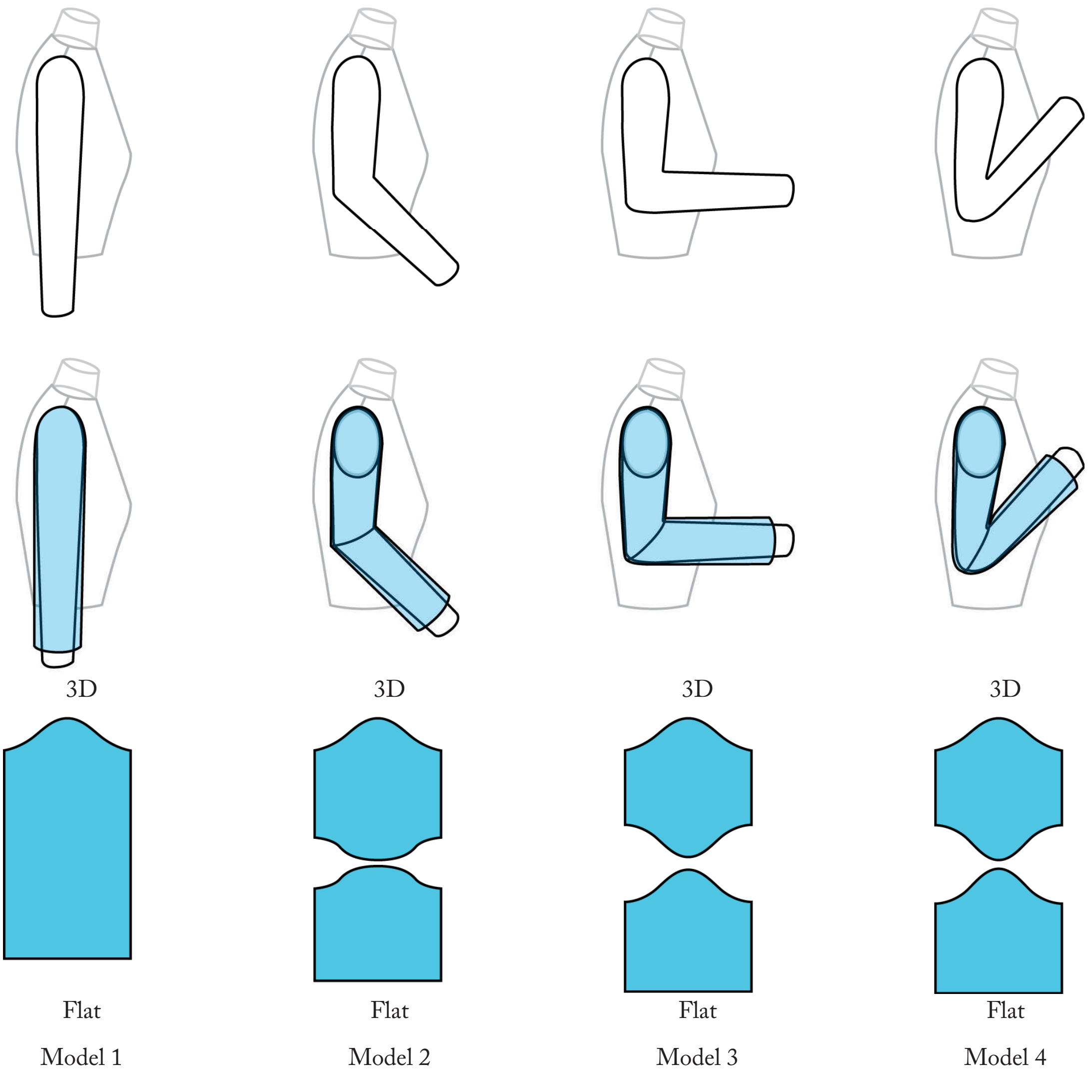


Figure 2: A series of patterns draped on the arm in different positions.

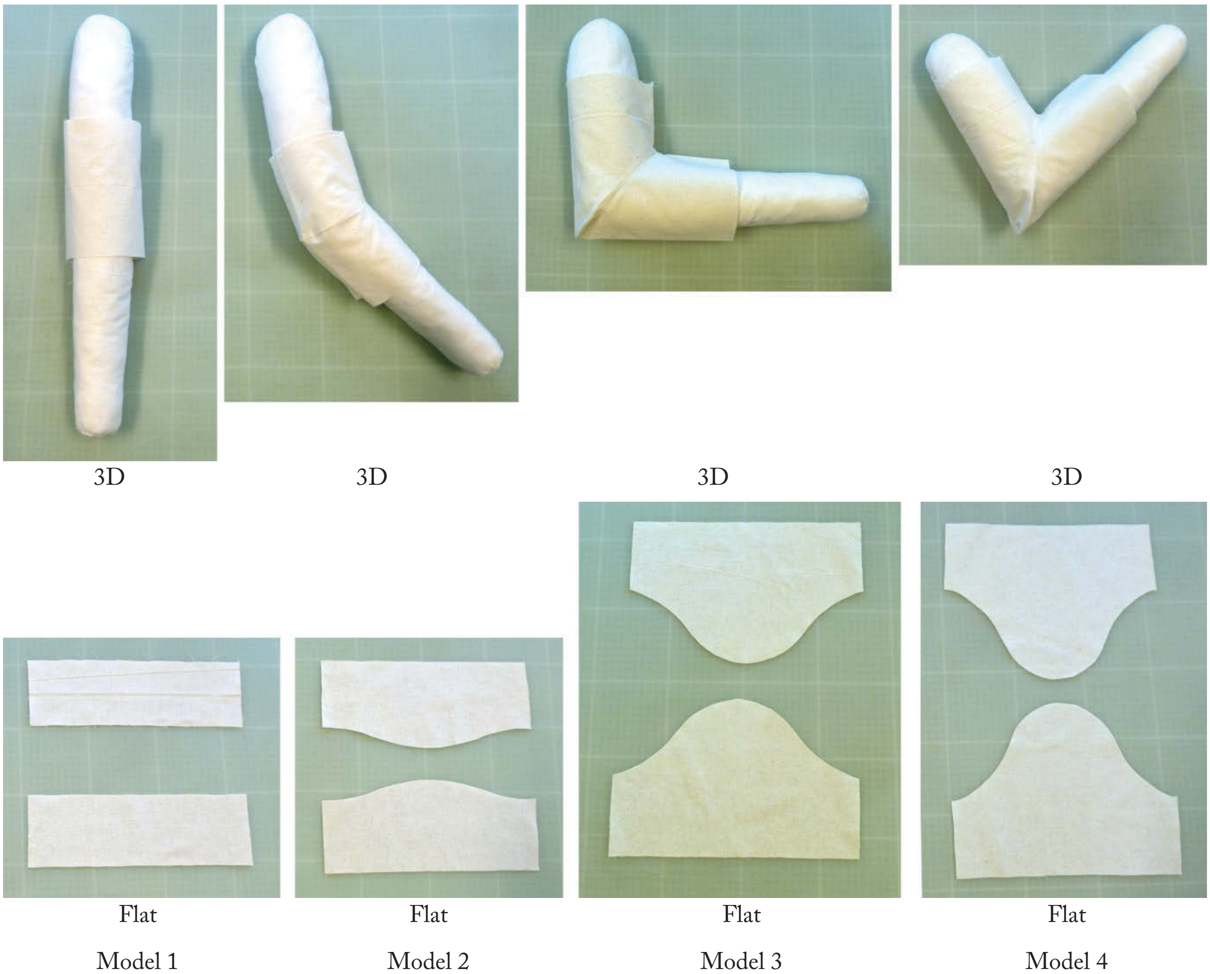


Figure 3: Fabric models of **Figure 2.**

Observations

It is observed from a geometric perspective that the initial pattern is a cylinder with flat Euclidean geometry (model 1). When the arm is bent at 90°, the top part of the elbow becomes a saddle shape with hyperbolic geometry (see figure 4). The tip of the elbow becomes a round shape with spherical geometry (figure 4). Using contour manipulation it is seen how the shape of the elbow pattern changes in time (see figure 5). The initial pattern has a straight line (the green line) in which the more the elbow bends the more curved the pattern becomes (the purple line). A curved pattern takes the shape of a Sine wave. The curvature on the pattern's top gives the elbow spherical geometry, while the curves on the bottom give the inside of the elbow hyperbolic geometry.

Draping these flat patterns with fabric is one way to see how the pattern shape changes in time. Another way of finding curved patterns is through Mnatsakanian's visual calculus techniques (2012).

When the arm bends, it is like joining two cylinders that have been cut at an angle. From a geometric perspective this equates to finding the shape of the cylinder's cross-section. Visual calculus uses physical models instead of numerical calculations (see figure 6). One method involves dipping a paint roller into paint at an angle. When rolled onto a piece of paper the area not covered by paint creates the flat pattern. A similar procedure is to wrap a piece of paper around a wax candle and cut the cylinder at the desired angle (see figure 7). The pattern shape is then laid flat to reveal the pattern of the cross-section. Here then, are several options for mapping the phenomenon of the bend join.

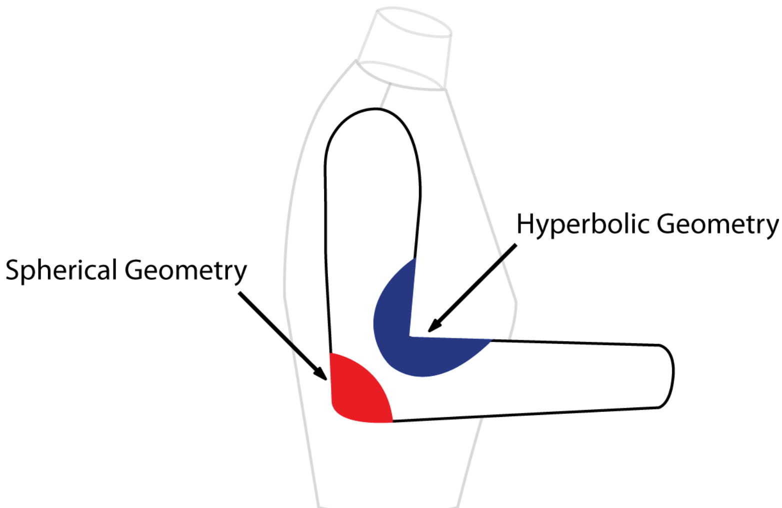


Figure 4: The outside of the elbow on a bent sleeve has spherical geometry, while the inside of the sleeve has hyperbolic geometry.

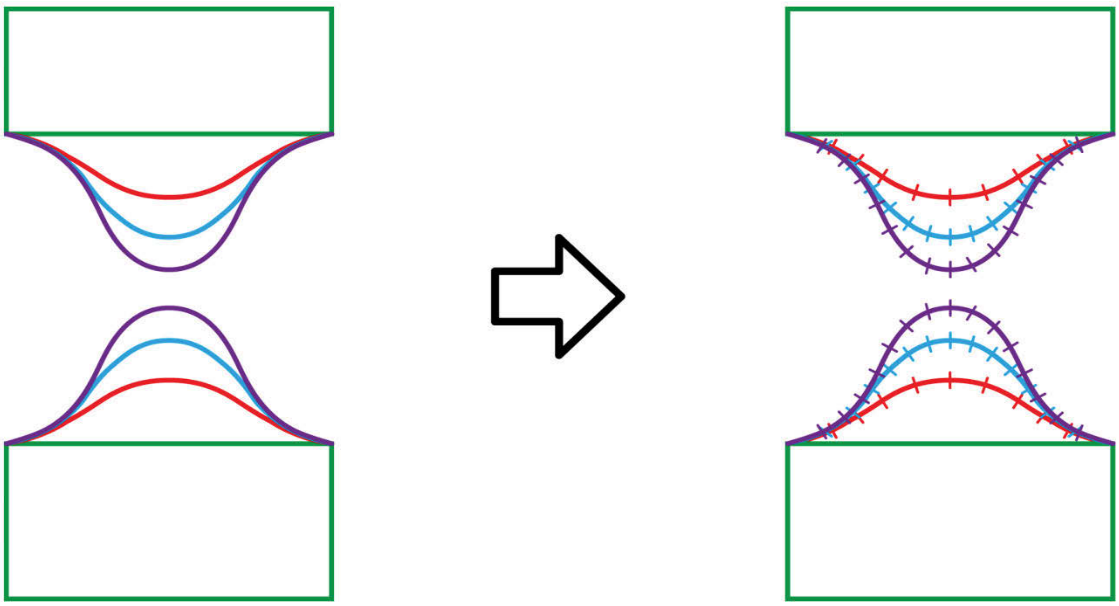


Figure 5: Using contour manipulation it is possible to analyse the shape of the elbow pattern as it changes in time.

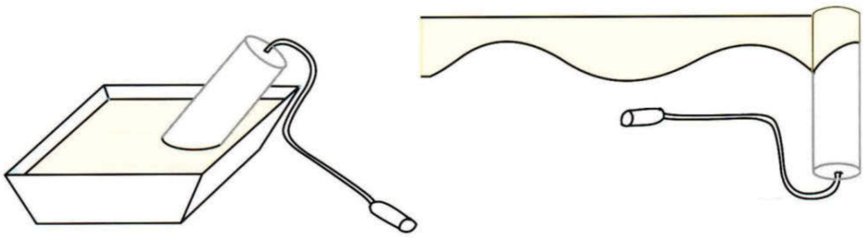


Figure 6: To find the cross-section of a cylinder, dip a paint roller into paint at an angle and roll it onto a flat sheet of paper to find the flat pattern (Mnatsakanian 2012, p. 172).

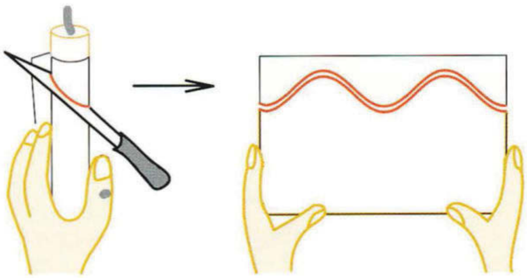


Figure 7: To find the flat pattern of a cross-section of a cylinder, roll a piece of paper around a cylinder and cut down the candle with a knife. Flattening the paper will reveal the flat pattern (Mnatsakanian 2012, p. 172).

Conclusion

The experiment shows that bending the arm creates a series of flat patterns. The pattern starts as a Euclidean tube. The more the elbow bends, the more the inside of the elbow becomes hyperbolic and the more the outside become spherical. This can be described from a geometric perspective as joining two cylinders with their ends cut off at different angles. Using visual calculus it maps the same shapes draped on the sleeve by use of physical models. Mapping the bend joint, which appears in many places on the body, should help patternmakers understand body movement in greater depth.

Experiment 55: Mapping Rotational Joints

Rationale

This experiment maps as a series of flat patterns the shape of an arm as it rotates around the shoulder. It explores the nature of "rotational joints" and how these affect the flat patterns they engender.

Hypothesis

The research anticipates that sleeves attached to the shoulder will create wrinkles if the arms move to different positions. If the sleeve is not attached to the armhole these wrinkles may not be there. By mounting sleeves in different positions into the garment's armholes, it can be observed how a pattern changes as the arm rotates.

Experimental Design

The experiment seeks to map the arm's range of motion as it rotates around the body. The arm shape is recorded as a series of flat patterns. The shoulder has a wide range of movement owing to ball and socket joints (see figure 1). These allow a limb to pivot around a single point to create complex movement. This can be observed at the top of the sleeve. In the experiment the sleeve is not permanently attached to the armhole. Instead it is mounted in different positions that pivot around the centre of the arm. Mapping the sleeve's motion shows how the sleeve pattern rotates around the pattern.

Procedure

Model 1: Start with a basic garment block pattern and mount a sleeve into the armhole so that the sleeve points to the back of the garment and faces 45° away from the ground. Sew the sleeve into the armhole.

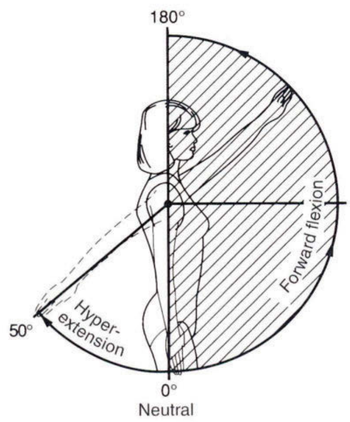
Model 2: Detach the sleeve from the armhole. Rotate the sleeve 45°anti-clockwise and mount it into the armhole so that it faces towards the ground.

Model 3: Detach the sleeve from the armhole. Rotate the sleeve 45° anti-clockwise and mount it into the armhole so that it faces 45° towards the front of the garment.

Model 4: Detach the sleeve from the armhole. Rotate the sleeve 45° anti-clockwise and mount it into the armhole so that it faces 90° towards the front of the garment.

Model 5: Detach the sleeve from the armhole. Rotate the sleeve 45˚ anti-clockwise and mount it into the armhole so that it faces 135˚ towards the front of the garment.

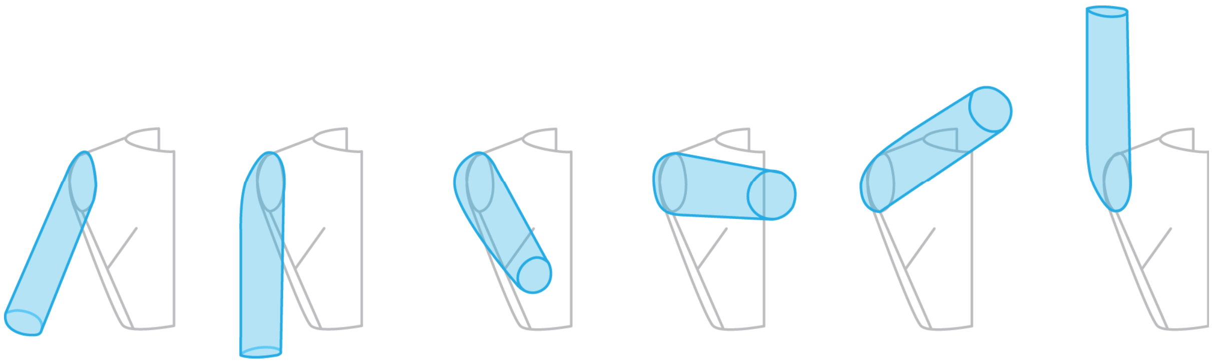
Model 6: Detach the sleeve from the armhole. Rotate the sleeve 45˚ anti-clockwise and mount it into the armhole so that it faces 180˚. The garment is now posed with its arms in the air and pointing above the garment.



The range of motion of the shoulder joint. (Hamilton & Luttgens 2002, p. 562)

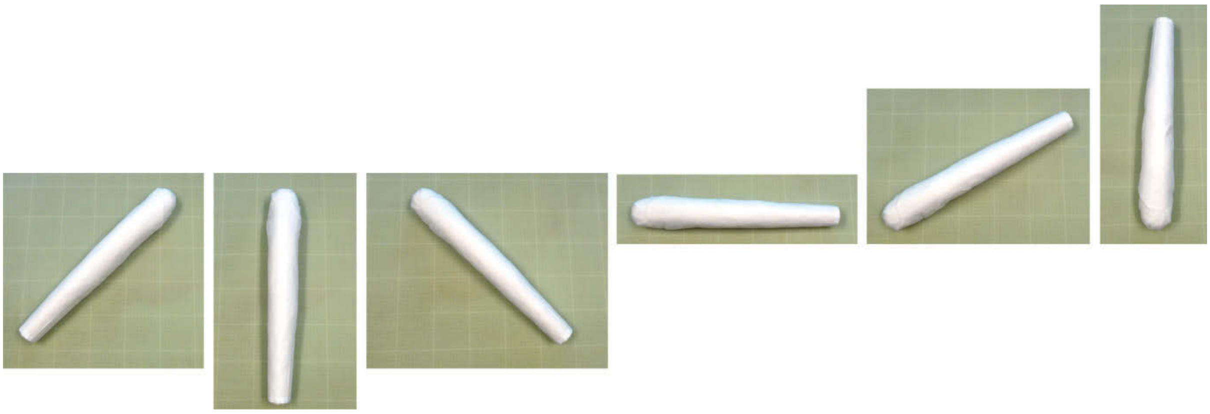
Figure 1: Ball and socket joints facilitate a wide range of body movement.

Results



Model 1 Model 2 Model 3 Model 4 Model 5 Model 6

Figure 2: If the sleeve is not permanently sewn into the armhole, it can be mounted into the armhole and rotated as the arm moves.

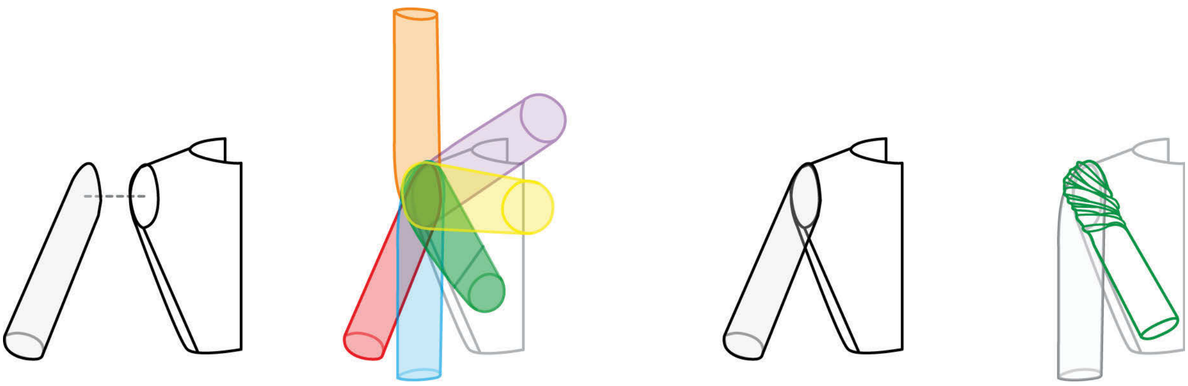


Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6

Figure 3: Fabric model of **Figure 2.**

Observations

It is observed that if the sleeve is not attached to the armhole it can freely rotate and does not create wrinkles (see figure 4, below). When the sleeve is sewn into the armhole, the movement of the arms causes the pattern wrinkles (see figure 4). The sleeve is usually positioned to fit downward in one default position. The wrinkles created by the pattern suggest that a single static flat pattern shape can never perfectly capture the changing shape of the shoulder. In order to perfectly fit the shape of the body, the pattern would have to be detached and sewn into a new position each time the arm moves. This makes it almost impossible using conventional patternmaking techniques to create a sleeve that does not wrinkle. Alternatively, the research would have to invent a pattern that could dynamically change shape.



A sleeve disconnected from the armhole can easily rotate around the body as the arm moves without creating wrinkles.

A sleeve sewn into an armhole creates wrinkles when the arm moves.

Figure 4: As soon as a sleeve is sewn into an armhole, any movement of the arm creates wrinkles on the sleeve.

Conclusion

The experiment shows that a sleeve best fits the body when mounted in the armhole at the same angle as the arm. When positioned thus, it creates no wrinkles. In conventional patternmaking the sleeves of garments are positioned to face the ground, and the default shape of a garment has the wearer with their arms by their sides. However, arms are constantly in motion, mitigating against a perfect fit. A pattern that could rotate around a joint without creating wrinkles may have a better fit than a conventional pattern. In sum, it demonstrates how dramatically body movement changes the shape of flat patterns.

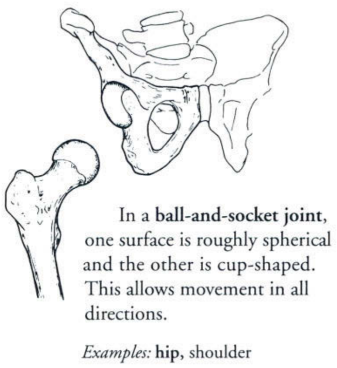
Experiment 56: Mapping the Hip Joint

Rationale

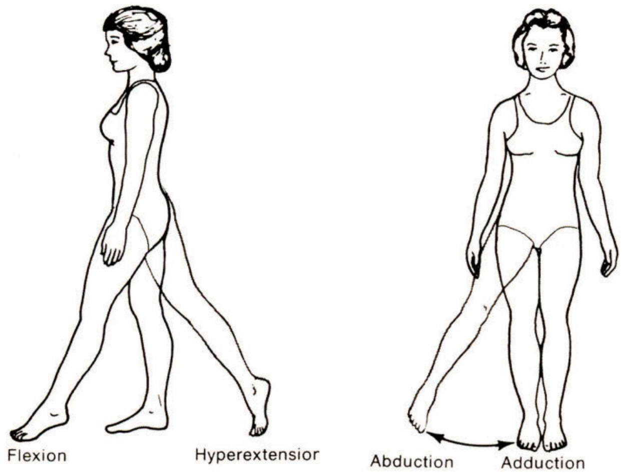
This experiment seeks to understand the range of motion created by the hip joint. It makes observations of the hip's range of motion captured by anatomy books. Following this, it analyses how the range of motion affects the shape of the pattern. Such a complex range may be overwhelming for patternmakers to map, so the research seeks to distil it into simpler motions, by using of a series of diagrams.

Hypothesis

The research anticipates that the movements of the hip joint may change the pattern in a similar way to a bend joint. Others may affect the pattern in the manner of a rotational joint, since the hip joint has a ball and socket (see figure 1).



A ball and socket joint
(Calais-Germain 1991, p. 9).



The range of motion of the hip joint.
(Hamilton & Luttgens 2002, p. 168)

Figure 1: Ball and socket joints facilitate a wide range of body movement.

Experimental Design

The experiment makes observations on the hip's range of motion and how it affects the pattern shape, as well as similar observations from an anatomy text (see figure 2). Using these observations, draw poses that simplify this complex range of motion into patterns that identifies these joints.

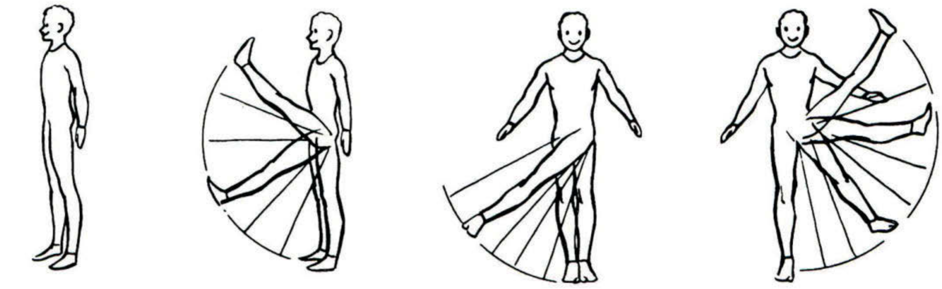


Figure 2: The hip joints create a complex range of motion (Fitt 1996, p.63).

Procedure

After observing the range of motion in the anatomy text (see figure 2), distil the movement into simple forms that will affect the shape of a pattern.

Model 1: Draw a basic trouser in three dimensions. Draw in red the leg as it is extended to the side (or in a position of abduction).

Model 2: Draw a basic trouser in three dimensions. Draw in blue the leg as it is extended in front of the body (or in a position of flexion).

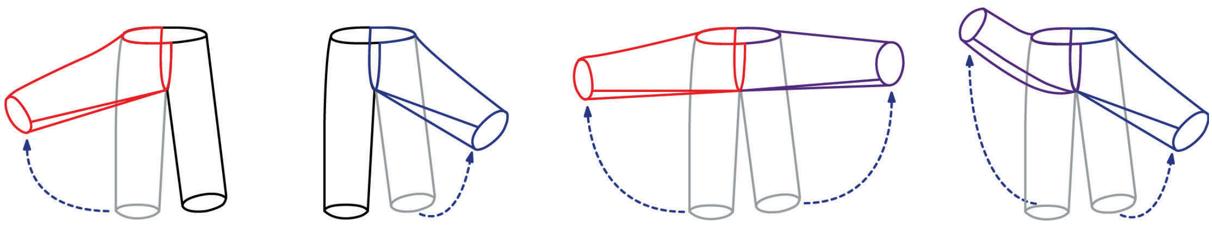
The next two models push the motion of the patterns to extremes by pushing the legs into the forward and side-splits positions.

Model 3: Draw in grey a basic trouser in three dimensions. Draw in red and purple the leg as it is extended to the side-splits position.

Model 4: Draw a basic trouser in three dimensions (in grey). Draw in purple and blue the leg as it is extended to the front-splits position.

Observe how these patterns would affect the pattern and which kinds of joints they use.

Results



Model 1:
Bend to the side.

Model 2:
Bend to the front.

Model 3:
Side splits.

Model 4:
Front splits.

Figure 3: The complex range of motion at the hip joint creates a combination of a bend joint and rotational joint.

Observations

It is noted that the movement in model 1 resembles that of a bend joint. In this pattern, the tube-shaped leg is tilted at different angles as the wearer moves their leg (see figure 4). Model 3 is like a bend joint when the joint is straightened.

In model 2, the forward movement of the leg resembles a rotational joint as the leg pivots around the hip's ball and socket joint (see figure 6). Model 4 re-enacts where each leg is rotated in an opposite direction.

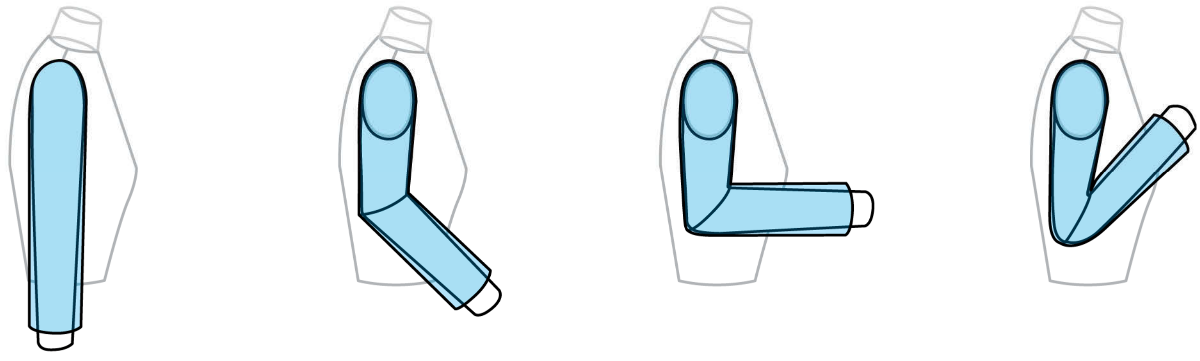


Figure 4: An example of the bend joint.

Figure 5: A fabric model of **Figure 4.**

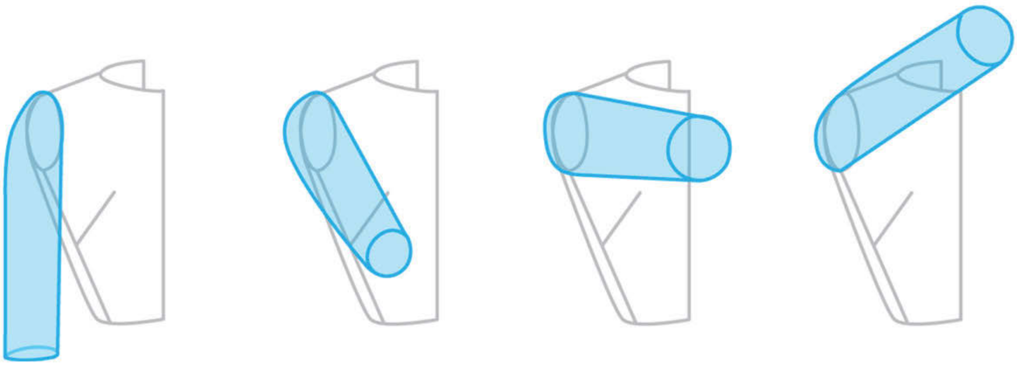


Figure 6: An example of the rotational joint.

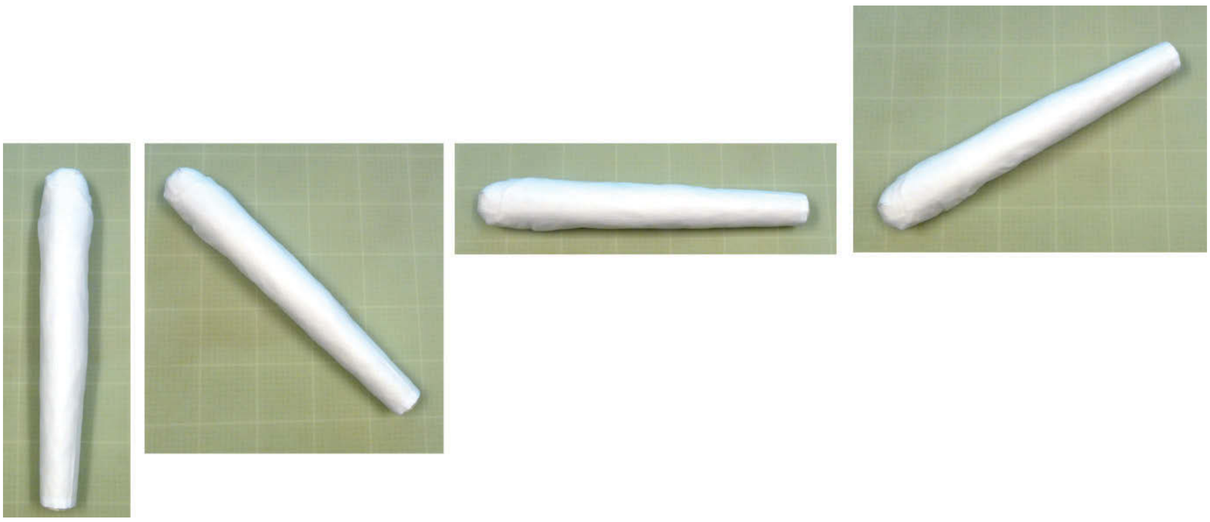


Figure 7: A fabric model of **Figure 6.**

Conclusion

The hip joint is one of the most complex in the body. It is noted that it behaves like a combination of a bend joint and rotational joint. From a patternmaking point of view, the range of motion when raising the legs can be described as a variety of bend joints. Forward walking motion can also be described using rotational joints centred at the hip's ball and socket joint (see figure 1). In sum, this range may look complex, but it can be clearly deconstructed it into a combination of bend and rotational joints.

Experiment 57: Mapping The Shoulder Shrug

Rationale

This experiment maps the shoulder's range of motion and how it affects the pattern shape over time. The shoulders are among the most complex moving parts of the body and their range of motion can be daunting for patternmakers to measure. The research consults anatomy books to better understand the movement of the different bones and muscles. Following this, it maps them as a series of flat patterns over time.

Hypothesis

The research anticipates that after consulting anatomy texts, it can simplify the range of motion created by the shoulders. This should help patternmakers grasp how these movements affect the pattern shape.

Experimental Design

The experiment seeks to map the shoulders' range of motion as a series of flat patterns. The shoulder joint is one of the body's most complex joints, and its motion must be broken down into simpler movements. In previous experiments, the research identified that the shoulders have a ball and socket joint that lets the arm rotate. From a patternmaker's perspective this movement can be captured using a rotational joint. Yet the shoulders have the ability to shrug, which is a movement separate from rotating the arm.

According to anatomy books (see figure 1, below) the shoulder shrug is controlled by a series of bones and muscles called the shoulder girdle (Calais-Germain 1991, p. 105). It consists of the scapula, clavicle and sternum (see figure 1). The scapula or shoulder blade attaches to the arm by a ball and socket joint (see fig 2). The scapula floats on top of the ribcage, allowing it to move in many different positions (figure 3). The movement of the shoulder girdle makes it possible to shrug, allowing a wide range of motion (see figure 4). Using these anatomical texts as a reference, it is possible to map the shoulders' range of motion.

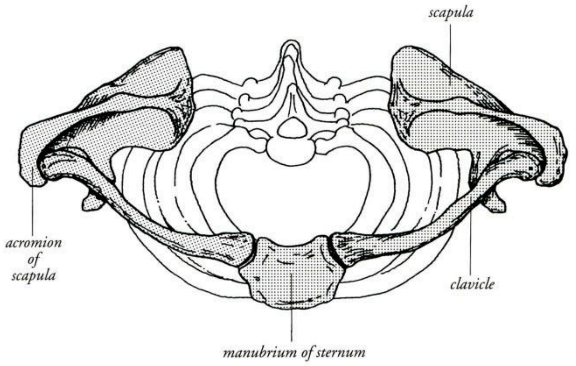


Figure 1: The shoulder girdle (Calais-Germain 1991, p. 105).

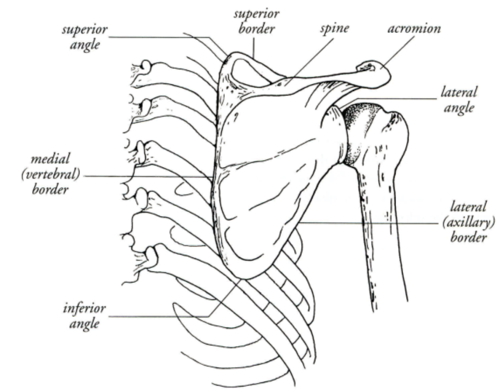


Figure 2: The scapula bone of the shoulder (Calais-Germain 1991, p. 107).

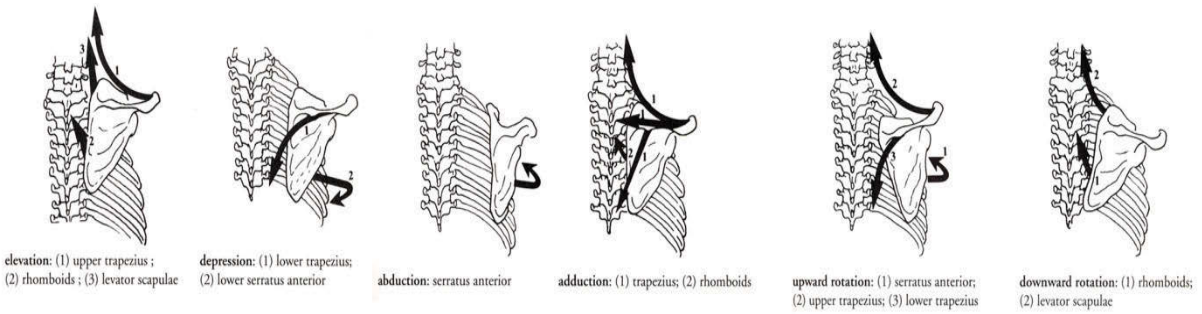


Figure 3: The different movements created by the scapula bone in the shoulder (Calais-Germain 1991, p. 119).

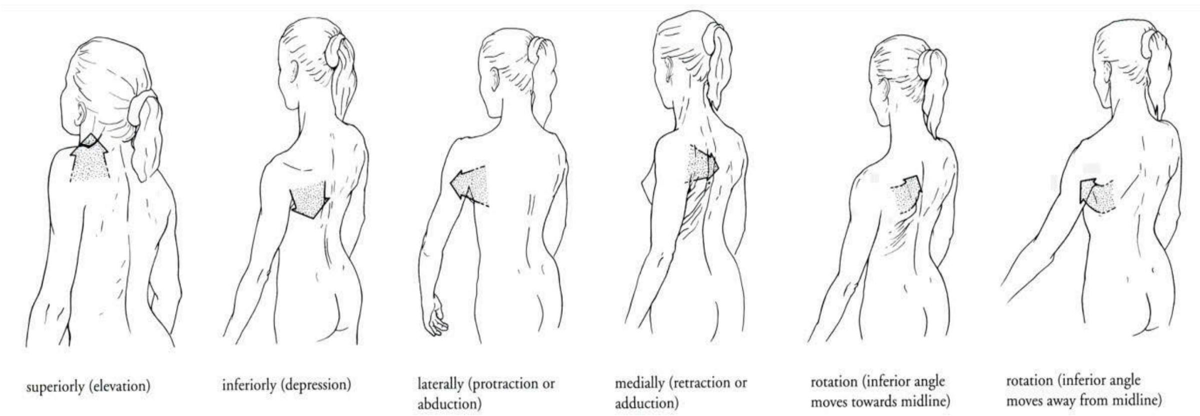


Figure 4: The range of motion of the shoulder joint (Calais-Germain 1991, p. 100).

Procedure

The experiment maps the different patterns created as the shoulders shrug through their range of motion. The shoulders shrug in a total of nine different directions. The patterns focus on the location of the armhole.

Model 1: Draw a basic garment block pattern.

For the rest of the models, draw the basic block in grey and draw a new coloured pattern on top.

Model 2: Draw (in red) a garment with the shoulders shrugged in an elevated position.

Model 3: Draw (in yellow) a garment with the shoulders shrugged, pointing diagonally forward and upward.

Model 4: Draw (in green) a garment with the shoulders shrugged, pointing forward.

Model 5: Draw (in brown) a garment with the shoulders shrugged, pointing diagonally forward and downward.

Model 6: Draw (in blue) a garment with the shoulders shrugged downward.

Model 7: Draw (in pink) a garment with the shoulders shrugged, pointing diagonally backward and downward.

Model 8: Draw (in light blue) a garment with the shoulders shrugged backward.

Model 9: Draw (in green) a garment with the shoulders shrugged, pointing backward and upward.

After creating these models observe how the position of the shoulders affects the location of the armholes in the pattern.

Model 10: Re-create models 1 to 9 and attach sleeves into the armholes.

Observe how moving the armhole changes the shape of the pattern.

Results

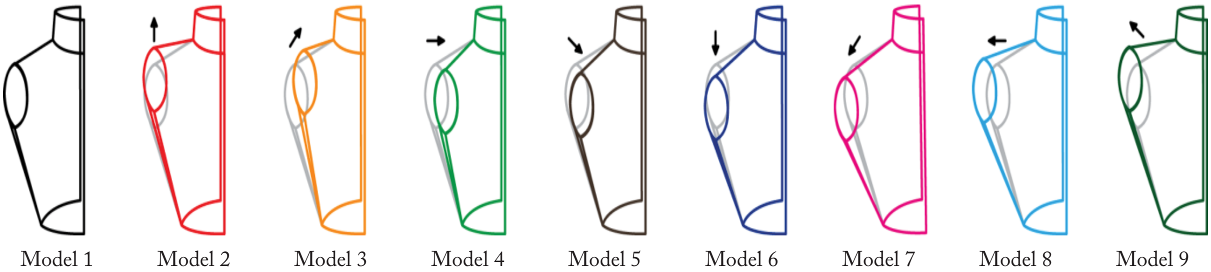


Figure 5: The range of motion of the shoulders as they shrug.

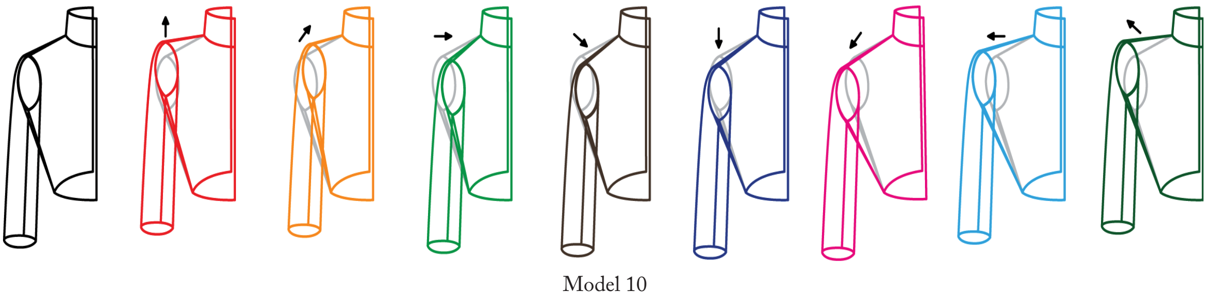


Figure 6: The range of motion of the shoulders as they shrug (with sleeves attached).

Observations

From a patternmakers point of view the shrugging of the shoulder changes the location of the armhole. Shrugging is a separate movement from the rotational joint of the arm, which relies on the sleeve rotating around the armhole (see figure 6). Moving the armhole changes the entire shape of the torso, lengthening one side of the pattern while shortening the other. If using a conventional pattern without moving the armhole, the tension of the pattern changes every time its moves its location. It is noted that shoulder-shrugging can make one side of the pattern stretch and become tighter while the other side becomes looser (see figure 7). This all suggests that a pattern that can change shape to suit the location of its armhole, will have a better fit.

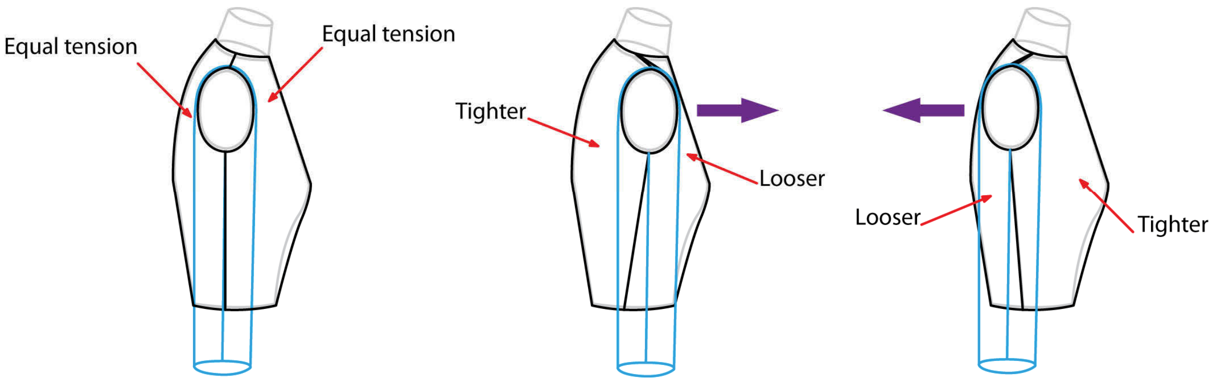


Figure 7: Moving the armhole adds material to one side and removes it from the other.

Conclusion

The experiment shows how the complex movement of the shoulder shrug can be described as moving the location of the armhole in a pattern. This gives patternmakers a much simpler way to describe this complex movement. In sum, a pattern that can move the location of its armhole around, will have a better fit to the body.

Experiment 58: Mapping The Deltoid

Rationale

This experiment maps the range of motion created by the deltoid muscle and how this affects the shape of the pattern in time. Due to the complex motion of the deltoid, the research consults anatomical texts to gain a better understanding. The goal is to simplify this motion into a series of patterns that patternmakers should be able to easily analyse.

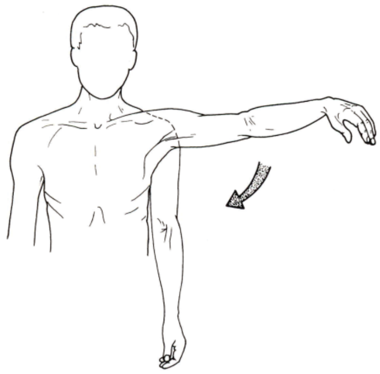
Hypothesis

The research anticipates that it can map the deltoid's range of movement as a series of flat patterns. For this purpose, it consults anatomical texts about the structure and function of the muscle.

Experimental Design

The experiment analyses the movement of the deltoid as a series of patterns over time. In previous experiments it is observed that the arm's ball and socket joint functions like a rotational join. It was seen that the shoulder could be shrugged by using the muscle and bones in the shoulder girdle. What makes the movement of the deltoid distinctive is the way it changes the shape of the shoulders when the arms are raised. The term for this movement is the "adduction of the arm" (see figure 1, below). This range of movement is caused by the contraction of the deltoid muscle (see figure 2) which creates a curved shape on the arm (see figure 3). This changes the geometry of the head of the sleeve.

The first part of the experiment makes drawings of a person as they slowly move their arms above their head. It focuses on the shape of the shoulders as the arms are raised. The second part tries to map the flat pattern of a garment as the arms are being raised. It particularly focuses on observing the head of the sleeve and the position of the armhole.



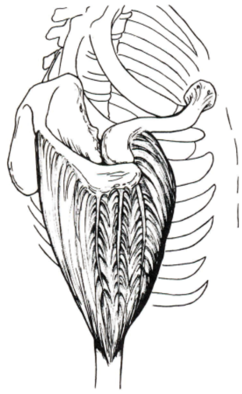


Figure 1: The range of motion created by the abduction and adduction of the arm (Calais-Germain 1991, p. 102).

Figure 2: The deltoid muscle in the arm (Calais-Germain 1991, p. 126).

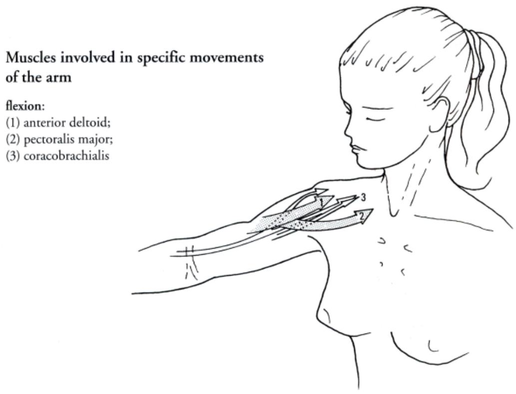


Figure 3: The muscles involved in raising the arm (Calais-Germain 1991, p. 127).

Procedure

<u>Part 1</u>:

The first iteration takes a model and traces an outline around the silhouette of their body. Then superimpose the different images on top of each other.

Model 1: Trace in red the outline of a model standing with their arms stretched out roughly 45° from the ground. Pose the model with arms out at 90° to the ground and trace in green. Trace in purple the model with arms extended 135° from the ground. Trace in blue the model with their arms raised above their head.

Observe how the shoulders change shape as the arms are raised.

Part 2:

The second iteration maps the pattern as the arms are raised about the head. This pattern is mapped as a three-dimensional pattern and as a flat pattern.

Model 2: Create a standard block pattern with a sleeve mounted in the armhole.

Model 3: Create a block pattern with the arm raised to a 45° angle to the ground.

Model 4: Create a block pattern with the arm raised to a 90° angle to the ground.

Model 5: Create a block pattern with the arm raised to a 120° angle to the ground.

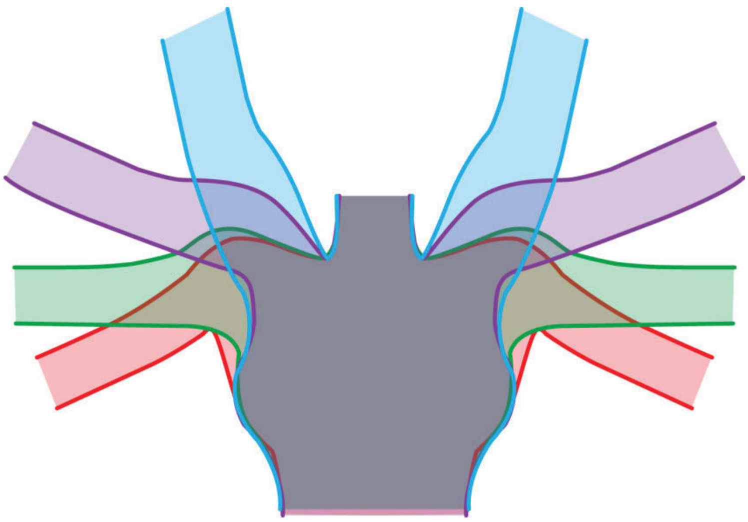
Model 6: Create a block pattern with the arm raised to a 145° angle to the ground.

Model 7: Create a block pattern with the arm raised to a 180° angle to the ground.

Observe how these patterns change the shape of the armhole.

Results

Part 1:



Model 1

Figure 4: Raising the arms changes the shape of the body.

Observations

It is observed that the top of the shoulder becomes more spherical in its geometry, while the underarm becomes more hyperbolic in shape (see figure 5). When the arms are pointing to the ground, the area under the arms is hyperbolic and the top of the shoulders is spherical. As the arms are raised, the underarms become less hyperbolic and the top of the shoulder becomes less spherical. The deltoid muscle itself creates a distinctive rounded shape on the arm even when the arms are raised above the head.

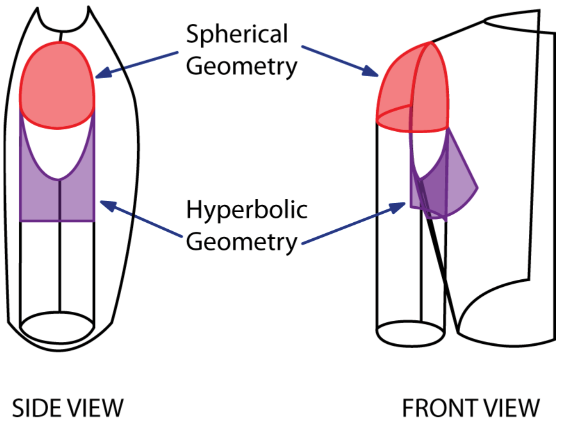


Figure 5: The top of the shoulder has spherical geometry, while the underarm has hyperbolic geometry.

Part 2:

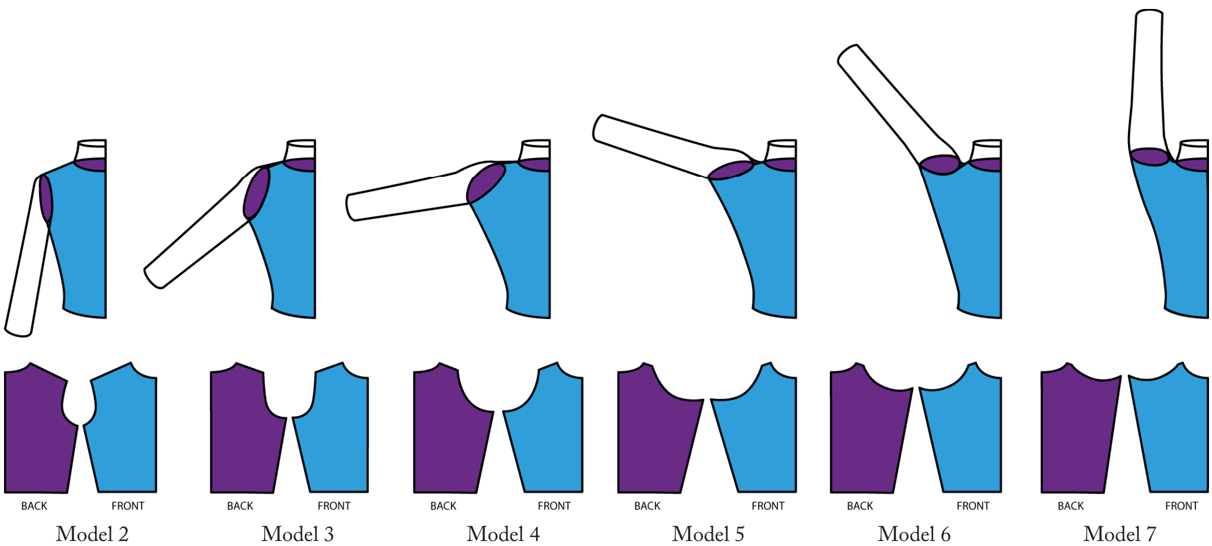


Figure 6: The range of motion created by raising the shoulders and the flat patterns they create.

Observations

It is observed that the changing shape of the shoulder is created by the changing position of the armhole. Unlike the shoulder's shrugging action, the deltoid tilts the armhole at an angle. In model 1 the armhole is vertical, by model 4 it is tilted 45° and by model 7 it is tilted 90° from the original position. Tilting the armhole requires the underarm of the pattern to be extended. Viewing the movement of the deltoid as an armhole pattern that tilts over time, is an effective way to simplify the changing geometry of the pattern (see figure 7).

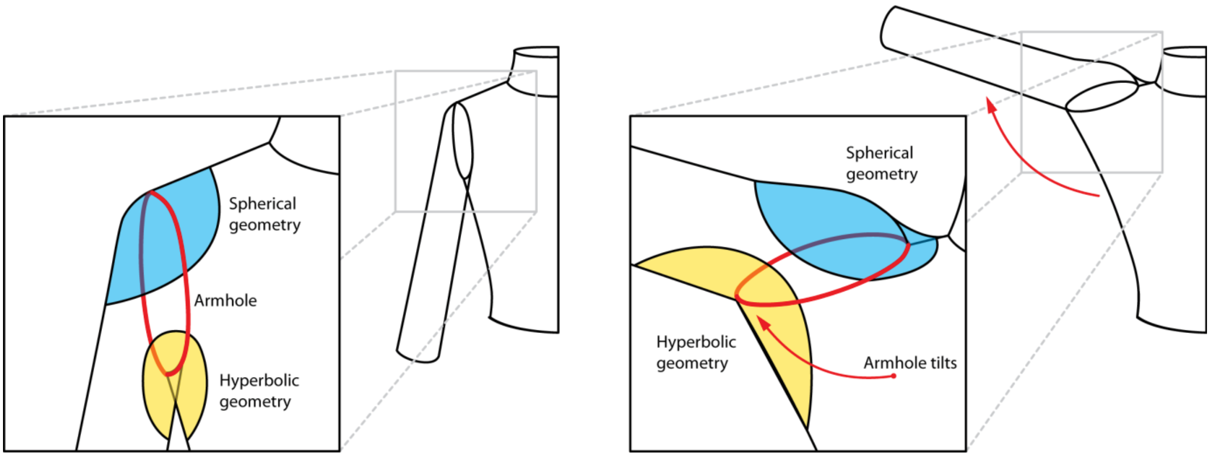


Figure 7: Raising the shoulders alters the geometry of the patterns.

Conclusion

The range of motion of the deltoid can be described by tilting the angle of the armhole of a pattern in time. This creates the shape of the deltoid as the arms are raised. The combination of deltoid movement, shoulder-shrug movement and arm rotational joint movement combine to make up the shoulders' complex range of motion. Conventional patterns do not move the location of their armholes. Understanding the range of motion will help patternmakers build more effective patterns.

Experiment 59: Sitting Down is Complex

Rationale

This experiment observes the joints and movements that make up the action of sitting down. Sitting down as an action is taken for granted in patternmaking. By analysing the complex range of movement, the research discovers how they affect the shape of the pattern.

Hypothesis

The research anticipates that the act of sitting down should involve multiple bending and rotational joints that will affect the pattern shape in a way similar to bend and rotational joints.

Experimental Design

The experiment is designed to show how the action of sitting affects the shape of a trouser pattern. The first part analyses the shape of the body in a standing and sitting position. It examines the different joints and anticipates how these would affect the body shape. The second part creates garment patterns in the standing and sitting position. Most trousers and made to fit the wearer in a standing position while few garments are draped to fit a sitting position. Using contour manipulation and patternmaking techniques for people with disabilities, it is possible to create a pattern for the sitting position. Following this, the research analyses the act of sitting and how it changes the pattern shape.

Procedure

<u>Part 1:</u>

The first iteration analyses illustrations of the body in standing and sitting positions, drawn in front and side views. The illustrations are annotated to show the different joints that change the body shape.

Model 1: Draw an illustration of the body from a reference image of a model in standing position. Draw the model in front and side views. The model should be wearing a top and trousers.
Model 2: Draw an illustration of the body from a reference image of a model in a sitting position. Draw the model in front and side views. The model should be wearing a top and trousers.

After drawing the images, annotate the illustrations (in red) to show the places where the joints are and how the pattern has changed.

Part 2:

The second iteration analyses the body in a standing and sitting position. It takes the poses, records them as three-dimensional shapes, then deconstructs the shapes into flat patterns.

Model 3: Analyse the three-dimensional shape of the trousers in standing position. Deconstruct this pattern into a flat pattern.

Model 4: Analyse the three-dimensional shape of the trousers in sitting position. Deconstruct this pattern into a flat pattern.

Compare these two flat patterns and observe how much the pattern changes between a standing and sitting position.

Results

Part 1:

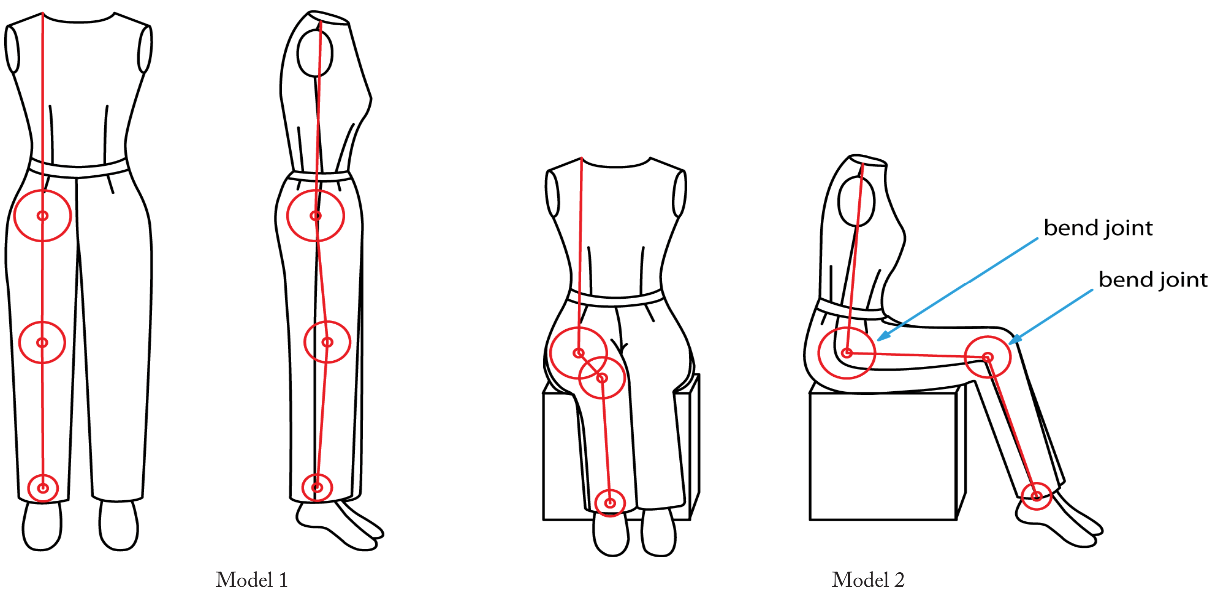


Figure 1: The standing and sitting figures have different three-dimensional shapes.

It is noted that the hip and knee behave like bend joints.

Part 2:

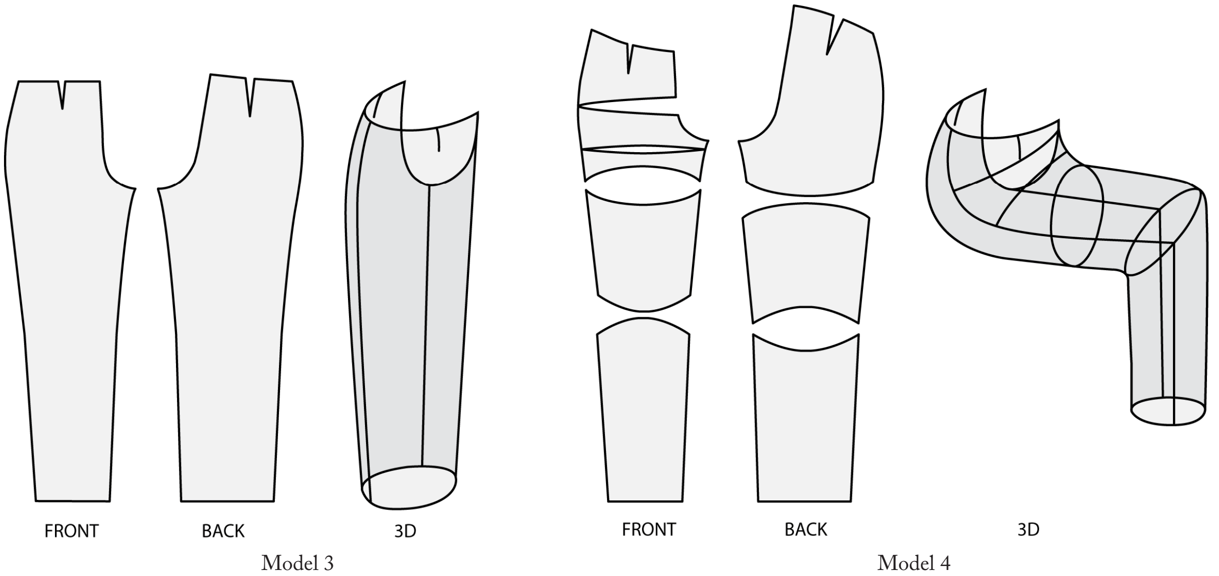


Figure 2: Standing and sitting figures have completely different three-dimensional shapes, requiring different shaped flat patterns. The flat trouser pattern is configured in a sitting position.

Patternmakers are familiar with the flat pattern of a trouser in a standing position (model 3). However, the pattern created of the wearer sitting down is very unconventional (model 4). The complexity of shape required to bend the knee and the hip 90° from each other is not often considered. The pattern's geometry also dramatically shifts from the standing to the sitting position. The initial standing position is created from a Euclidean-shaped tube (model 3), while the sitting position has many more spherical and hyperbolic surfaces. The bended shape creates spherical geometry at the kneecap and buttocks, while under the knee and top of the trouser front become hyperbolic in geometry.

Conclusion

The experiment shows the complex changes to the pattern shape when making the simple action of sitting down. Sitting dramatically changes the geometric properties of the garment, and patternmakers should be aware of these, to better understand both how to fit garments, and how movement affects the pattern shape.

Experiment 60: A Summary of the Range of Motion

Rationale

This experiment summarises the complex range of human motion that makes up the arms and shoulders. In previous experiments the research individually examined each of the bones and muscles that make a pattern change shape. Comparing the different mechanisms allows new observations to be made.

Hypothesis

The research anticipates that through a summary of all body movements, it can gain a clearer understanding of movement.

Experimental Design

The experiment compares the ranges of motion in the arm and shoulder. This summary is not the complete range of motion, but constitutes a basic framework that can be improved on depending on the detail of movement required. The future research should certainly be able to map movements in even finer detail. It places an emphasis on the translation of complex body movement into simple changes to a garment pattern.

Procedure

Compare the diagrams (from previous experiments) relating to ranges of body motion.

Diagram 1: The range of motion of an arm with a bend joint.

Diagram 2: The range of motion of an arm with a rotational joint.

Diagram 3: The range of motion of the shoulder girdle shrugging the shoulders.

Diagram 4: The range of motion of the deltoid muscle moving the arm above head.

Make observations about of the range of motions and how these affect the shape of a garment pattern. Explore if there are additional ranges of motion that can be added.

Results

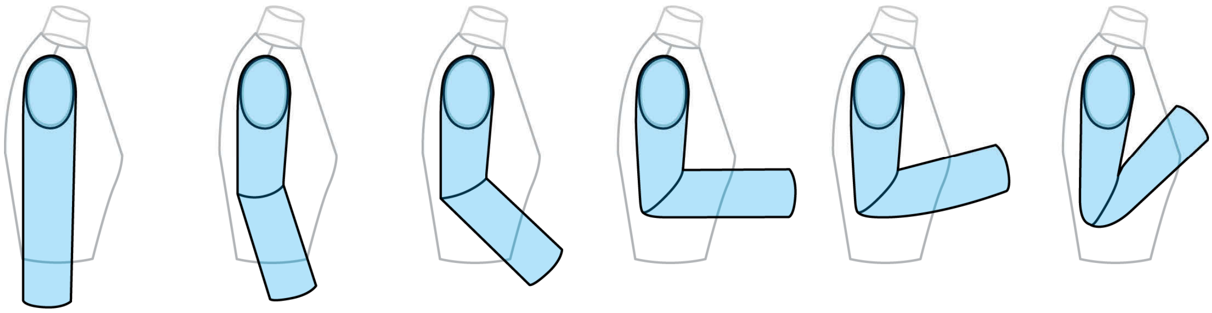


Diagram 1: Bend joint.

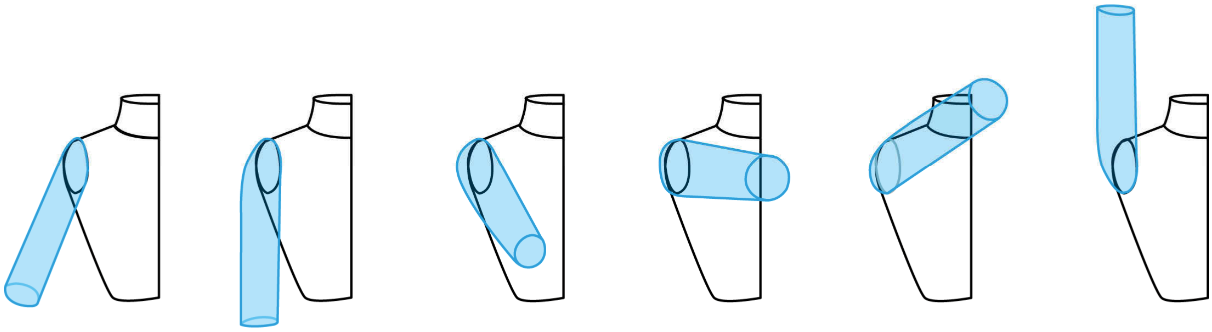


Diagram 2: Rotational joint.

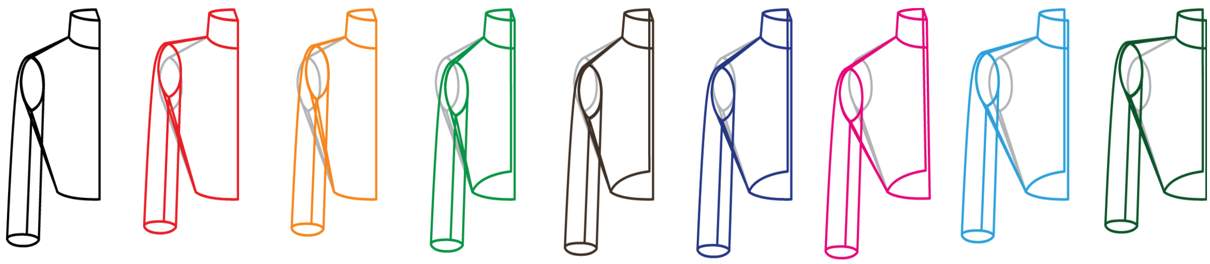


Diagram 3: Shrugging using the shoulder girdle.

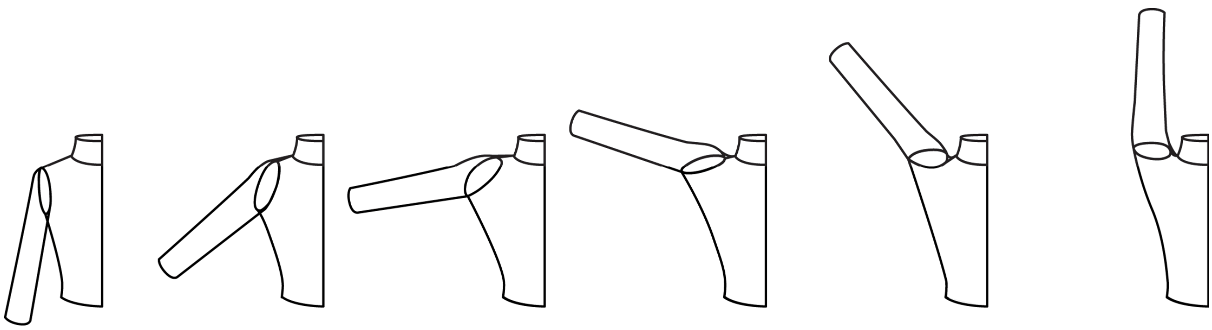
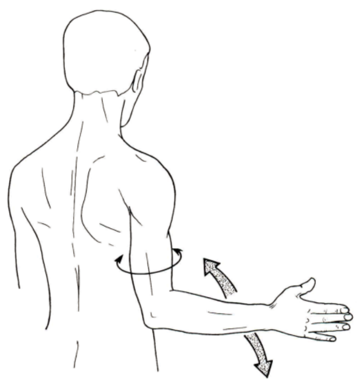


Diagram 4: Raising the arm using the deltoid.

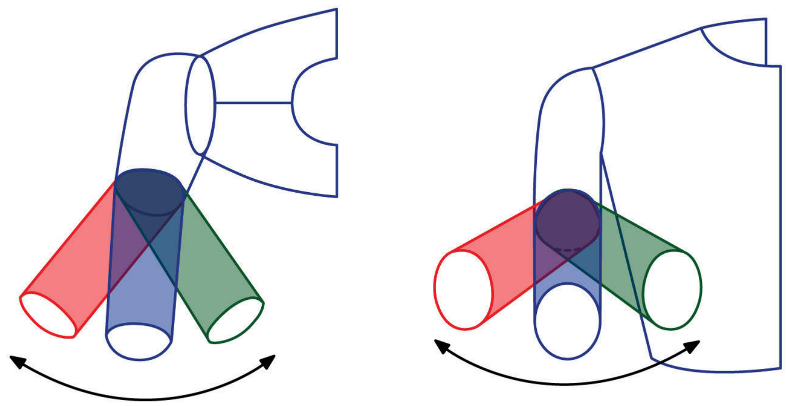
Figure 1: A summary of the range of motion of the arm.

Observations

In this summary of motion, there are three main ways to change the pattern. The first is to change the shape at the joint, for example the bend joint in diagram 1. The second is to rotate the sleeve around the armhole, as in diagram 2. The third is to move the location of the armhole by shrugging, as in diagram 3, or tilting the armhole with the deltoid as in diagram 4. These together seem to make up a significant range of motion. The only additional observation about movement is that the forearm can pivot left to right (see diagram 5, below). This motion is call the rotation of the humerus on its axis (Calais-Germain 1991, p. 102), and affects the bend of the elbow. On reflection, it seems possible to consider putting a rotational joint in the elbow (see diagram 6, below). Using the bend joint like an armhole and pivoting around this joint, allows additional range of motion in the arms.



Rotation of the humerus.



Top view. Front view.

Diagram 5: The arm rotating the humerus around its axis. (Calais-Germain 1991, p. 102).

Diagram 6: Rotating the sleeve around the elbow like a rotational joint increases the arm's range of motion.

Figure 2: The range of motion of the forearm.

Conclusion

The experiment offers a summary of the range of motion as a series of flat patterns. This is one way of mapping the complex range of human movement, and creates a framework on which patternmakers can build more detailed models. The goal is to create a detailed summary of movement according to the simplest possible patternmaking. In sum, bend joints, rotational joints and moving armholes are the main ways to manipulate the pattern.

16. Questioning the Current Paradigm of Fit

Experiment 61: **Questioning the current paradigm of fit**

Experiment 62: **A new paradigm of fit**

Experiment 63: **Alternative strategies to fit**

Aim

These three experiments question the current paradigm of clothing fit and offer an alternative approach. Patternmakers conventionally make garments that fit a single static shape, relying on the fabric to stretch and wrinkle to allow movement. Yet the body is constantly changing shape in time, and a single static shape has limited capacity to adapt. These experiments explore an approach that maps the body's changing shape, creating a pattern deliberately designed to anticipate the changing form. It requires the patternmaker to re-think the way they designs their patterns. These experiments moreover explore techniques developed by fashion technologists that allow patterns to change over time without the use of stretch fabrics or wrinkles.

Method

The first experiment questions the current paradigm of garment fit, which requires a single static shape to fit the body, relying on the fabric to stretch and deform to accommodate movement. The second experiment proposes an alternative paradigm of fit whereby a garment should be of a dynamic pattern designed to change shape in time. The third examines strategies used in fashion technology to create garments that can do exactly that, including those made from rigid materials that cannot bend or wrinkle.

Analysis

The goal is to design garments that anticipate the movement of the body. Viewing fit from this paradigm forces the patternmaker to observe how the body is continually changing shape. The simple act of breathing constantly alters the width of the chest, while eating and drinking changes the form and volume of the stomach. New approaches to fit must create patterns that change shape in time rather than relying on the material to deform about the body. The experiments also analyse techniques used by fashion technologists to create rigid garments that can change shape, concluding that most of their approaches have limited capacity to dynamically change the body's form. The research thereby anticipates the need to develop more sophisticated patterns that can dynamically change shape in time.

Experiment 61: Questioning the Current Paradigm of Fit

Rationale

This experiment analyses the fit of a garment as the body changes shape over time, challenging the current paradigm of "fit". In conventional patternmaking, garments are designed to fit a single static shape, yet any garment changes shape by deforming and wrinkling. Stretch fabrics have allowed patterns to fit a wider range of people, yet stretch fabrics as a paradigm still engender fitting, sizing and discomfort issues (Watkins 2011).

Hypothesis

The research posits new definitions of garment fit. Previous experiments that map ranges of movement generally show that body shape does not match pattern shape. Instead, they rely heavily on the fabric wrinkling or on the fabric's stretch properties.

Experimental Design

The experiment is designed to examine wrinkle patterns formed when the wearer bends their arm. By watching how the garment wrinkles over time, it is possible to make observations about the current method of garment fit. The garment is recorded as a three-dimensional illustration and as a flat pattern.

Procedure

When the wearer bends their arm over time, analyse the three-dimensional pattern shape and the flat pattern.

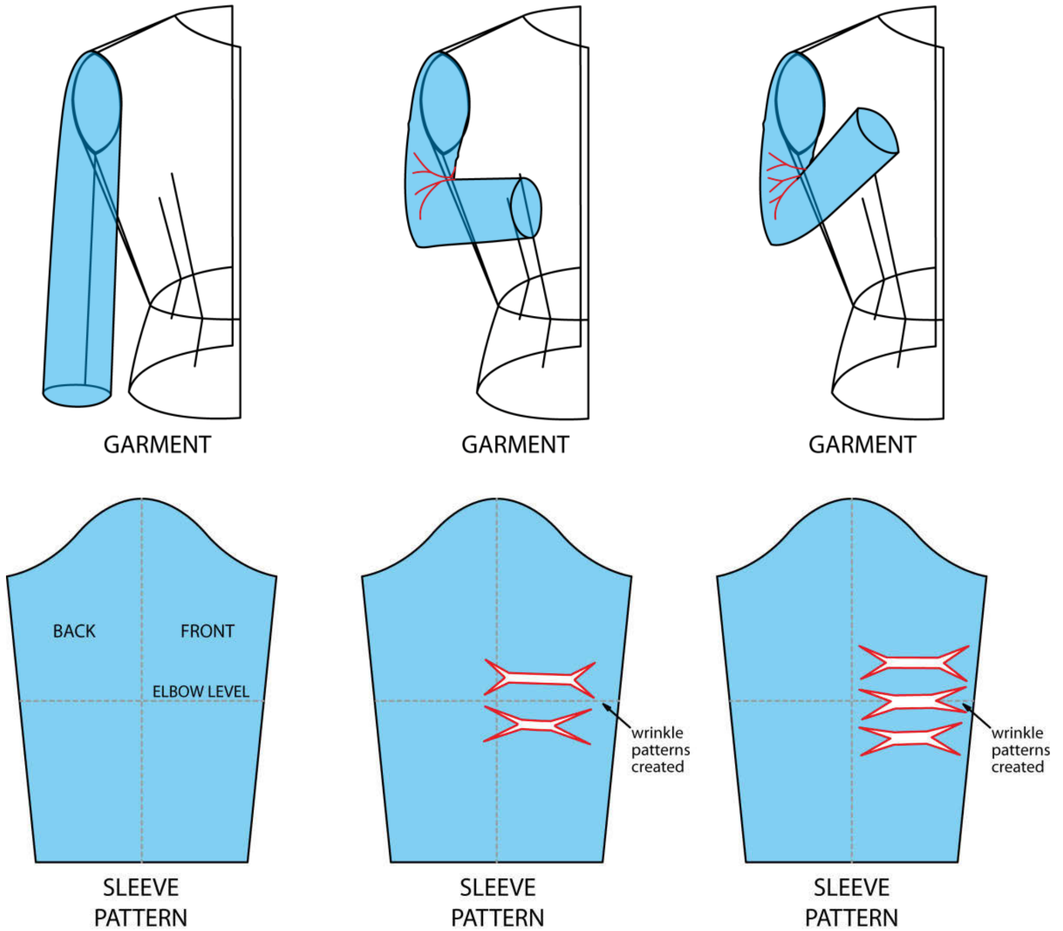
Model 1: Start with a basic block pattern, with a sleeve pattern set in the armhole.

Model 2: Have the wearer bend their arm so that it is 90° from the ground. Record the shape of the sleeve as a flat pattern.

Model 3: Have the wearer bend their arm so that it is 135° from the ground. Record the shape of the sleeve as a flat pattern.

After observing these patterns make observations about the pattern fit.

Results



Model 1: Default position of pattern.

Model 2: Arm bending.

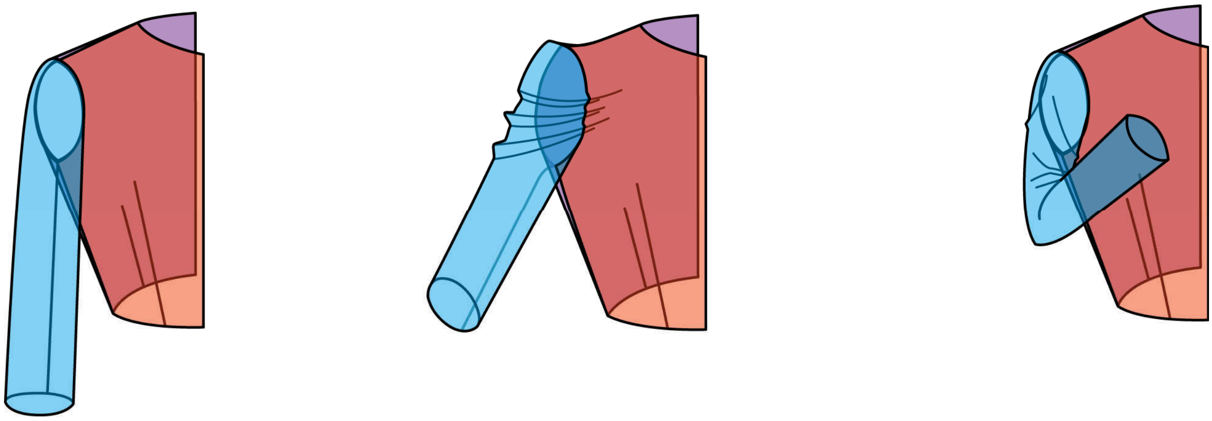
Model 3: Arm bending even further.

Figure 1: The more the arm bends, the less the pattern fits the original garment. This creates more wrinkles that can be mapped on the pattern using wrinkle analysis.

Observations

The original garment was designed to fit the body in a default position with the wearer's arms by their side (see model 1). As soon as the wearer bends their arms, the pattern shape and the body are not aligned. Wrinkles start to appear (models 2 and 3), and only by creating them can the garment still fit. Moreover, the more wrinkles the less the pattern fits the body shape. In fact, any movement of the arms, shoulders or elbows that diverges from the pattern's default position creates wrinkles (see figure 2, below).

Viewing the garment as a single static shape limits its ability to accurately fit. The previous experiments mapping the arm's range of motion reveal how much the body shape changes over time (see figure 3). A static pattern only fits the body for a single instant. Clearly, a definition of garment fit that includes how the pattern fits over the entire range of motion, would serve us much better.



Default position of pattern.

Movement of the shoulder.

Movement of the elbow.

Figure 2: If the body moves out of the default shape, the pattern will no longer fit perfectly and wrinkles will be created.

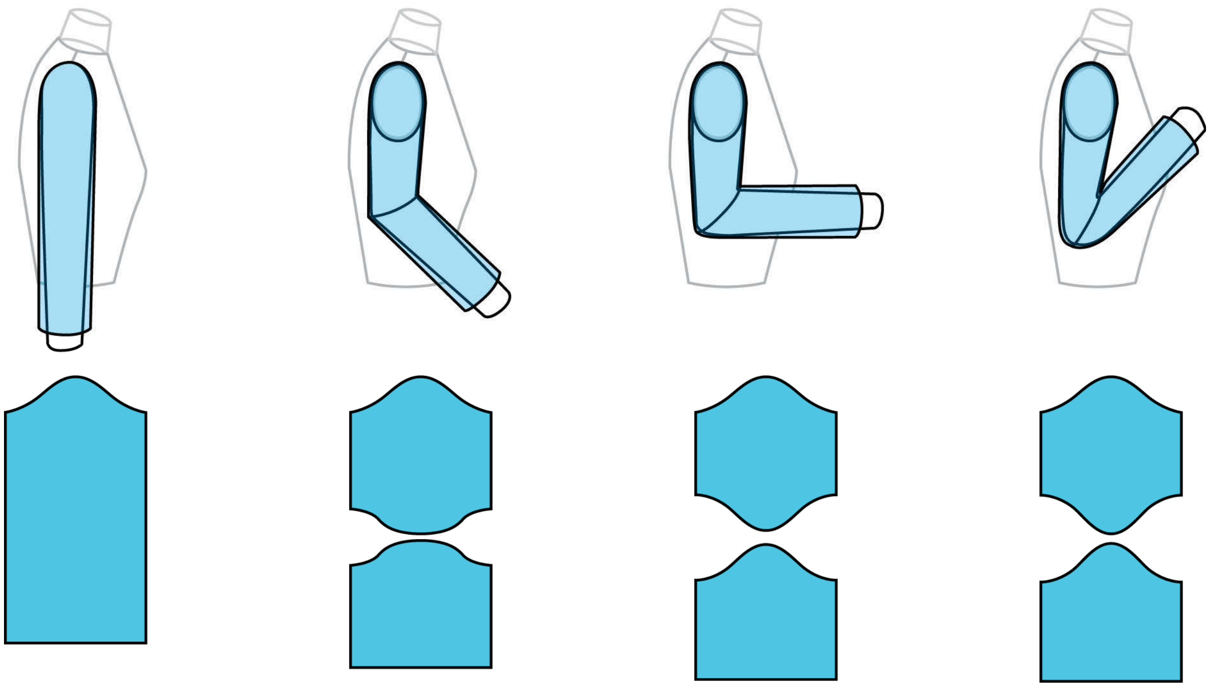


Figure 3: The range of motion of the bend joint, mapped as flat patterns. Each pose creates a pattern with a distinct shape.

Conclusion

The experiment shows that under the current definition a garment will fit a single default shape, and is dependent on the fabric to stretch and wrinkle to accommodate movement. A single static shape only fits the body in a single position in a single moment. After mapping the body's range of motion as flat patterns, it is observed just how much the body changes shape in time. To improve the comfort of clothing the research expands the definition of "garment fit" to mean "how well the pattern fits the body over time".

Experiment 62: A New Paradigm of Fit

Rationale

This is a thought experiment that seeks to redefine the concept of garment "fit", namely the creation of a hypothetical garment pattern that can change shape in time. Conventional patterns have a single static shape that fits the body for a frozen instant. They rely on the fabric to stretch and wrinkle to accommodate movement. This entrenches fitting problems and discomfort. It therefore seeks to re-define the concept of fit to accommodate the body shape over its entire range of motion.

Hypothesis

The research anticipates that by redefining the concept of fit to incorporate how well a pattern fits over time, it should create garments with a more comfortable fit. Patterns designed to change shape to fit the body in motion may well solve existing fitting problems, removing the reliance on wrinkles and fabric stretch. Further, garments that do not wrinkle could offer unique aesthetic effects.

Experimental Design

The experiment designs a hypothetical garment pattern that can change shape over time. Its pattern creates the shape of the bend joint as it changes to accommodate the shape of the wearer.

Procedure

Build a hypothetical sleeve pattern for a garment that changes shape to mirror the changing body shape.

Model 1: Start the pattern for a sleeve. The pattern is a cylindrical tube, with the elbow a rectangular pattern.

Model 2: Bend the arm. The rectangular pattern of the elbow should transform into a curved pattern. This changes the shape of the arm, making the bottom of the elbow more spherical in its geometry and the top more hyperbolic.

Model 3: Bend the arm even further. The curved pattern of the elbow should transitions a curve of greater height to accommodate the changing shape of the elbow.

Make observations on how this hypothetical garment would perform.

Results

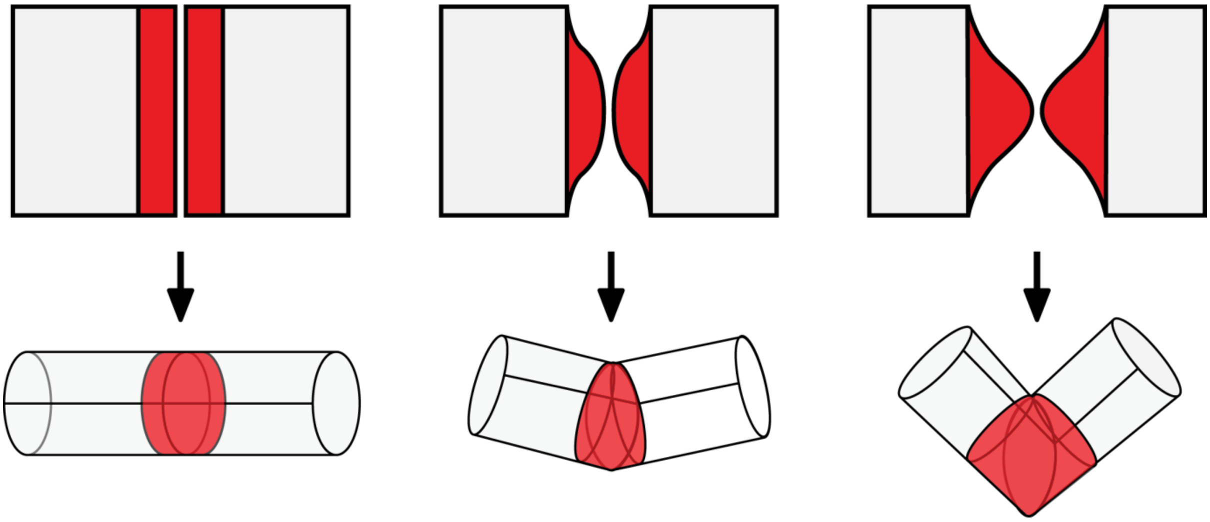


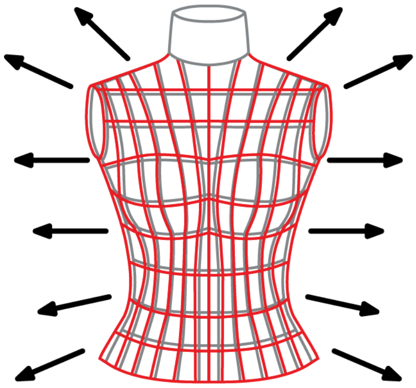
Figure 1: When the body is in motion, some parts of the pattern change shape while other parts stay the same.

Observations

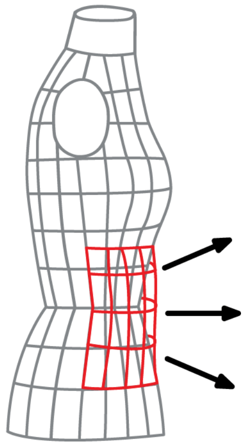
Even though this pattern is hypothetical, its ability to change shape offers increased comfort. A pattern that continually fits the wearer's shape also does not need to wrinkle, thereby creating a unique aesthetic. It is important that these patterns are built with knowledge of what the flat patterns of a bend joint look like, since patternmakers cannot anticipate the garment's pattern shape without having previously mapped a bend joint as a series of flat patterns.

Changing the definition of fit to include adaptation in time, forces the patternmaker to revaluate their practise. This definition of fit must be aware of the constant change the pattern to fit multiple poses, reminding us that the human body eats, breathes and is constantly changing posture. The chest is continually changing shape as humans breath in and out, while the stomach expands after eating (see figure 2, below).

Notwithstanding that this is a thought experiment, there are fabrics that can change shape in time. Existing technologies such as shape memory alloy or shape memory polymer, can do so (Lee 2005). These materials can be programmed to change shape as electrical current is run through them. At present they are cumbersome, slow and expensive, yet many fashion technologists speculate that memory materials will in time become commercially viable.



The chest expands when breathing.



The stomach expands after eating.

Figure 2: Variable geometry allows a garment to address the constantly-changing shape of the body. Bodily function such as breathing, eating and posture can change the pattern shape.

Conclusion

There are many advantages in creating pattern pieces that can change shape. Re-defining fit to include the entire range of motion creates patterns of increase sophistication, eliminating wrinkles and forcing patternmakers to build dynamic patterns that constantly adjust to the wearer. Beyond thought experiments, there still needs to be practical ways to create patterns that can change shape in time. Stretch fabric often deforms the desired shape, and shape memory alloys and polymers are cumbersome and impractical. The next experiment seeks alternate strategies to create better fit.

Experiment 63: Alternative Strategies to Fit

Rationale

This experiment explores techniques that patternmakers and fashion technologists use to create garments that can adapt to the changing body shape. In patternmaking it is often assumed that creasing and wrinkling help to accommodate movement, so that the ubiquity of wrinkles to facilitate movement is easily overlooked. The experiment posits alternative techniques to using wrinkles to allow movement.

Hypothesis

It anticipates that there are multiple strategies to achieve mobility in garments, beyond wrinkle creation.

Experimental Design

It begins by analysing pleats and the ways they stretch to accommodate body shape. Next, it investigates lacing and drawstrings. These in fact were a necessity for many garments before the invention of stretch materials. Finally, it tests more exotic types of joints from fashion technology. The stove pipe joint is made of rigid materials and uses rotational joints to change the pattern shape. The bellows joint expands and contracts to accommodate movement.

Procedure

Consider methods of creating fabric flexibility by observing diagrams.

Pleats

Models 1-2: Find an example of a pleats and pleating garments that can be used to control the garment shape or add flexibility.

Lacing and drawstrings

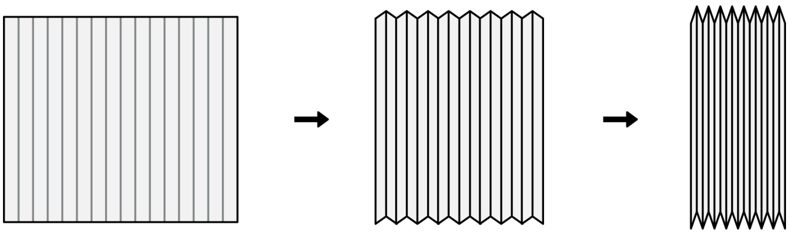
Models 3-4: Find examples of garments where lacing or drawstrings can be used to control the garment shape or add flexibility.

Stove pipe joints and Bellows joints

Models 5-6: Find examples of garments where stove pipe or bellows joints can be used to control the garment shape or add flexibility.

Results

Pleats



Model 1:

Pleats.

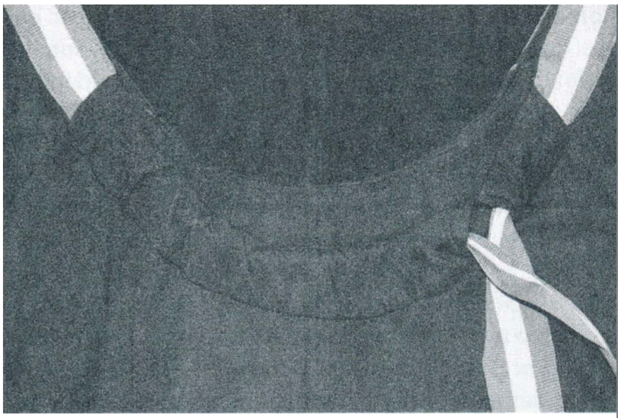
Model 2:

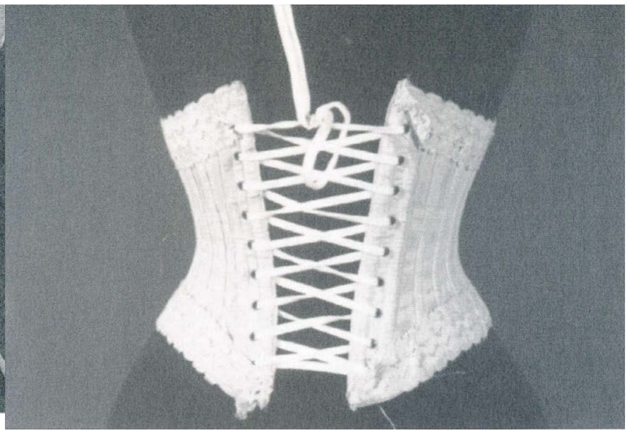
A pleated garment.

Figure 1: Pleats allows a large surface area to be compressed into a more compact structure.

Figure 2: Example of a pleated garment. (Miyake 2012, p .2).

Lacing and drawstrings





Model 3:

Drawstring.

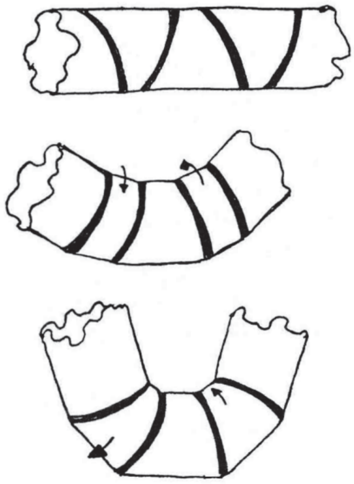
Model 4:

Laces and eyelets.

Figure 3: A drawstring runs through a channel in a garment so that the size can be adjusted (Bubonia 2012, p. 248).

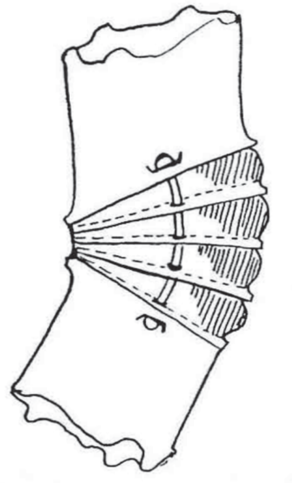
Figure 4: Running laces through eyelets is one way of adjusting the size and tension of a garment (Doyle 1997, p. 177).

Stove pipe and bellows joints



Model 5:

Stove Pipe Joint.



Model 6:

Bellows Joint.

Figure 5: Stove pipe and bellows structures allow movement in structures with rigid materials. (Watkins 1995, p. 263).

Observations

Many of these techniques have a similar effect to creating wrinkles. Pleats are essentially large, orderly-shaped wrinkles and creases, and use the same mechanism to get flexibility. Drawstrings control the shape of a garment, but the channel they run through wrinkles, creating the "wrinkle effect". The bellows joints is like a large pleat, with the bellows resembling an organised wrinkle structure.

There are two sets of techniques that do not rely on the fabric to wrinkle in the service of movement and flexibility. Laces and eyelets let the tension of the laces control the tightness of a rigid corset, in effect relying on lace tension to create flexibility. The stove pipe joint (figure 4) rotates its joints to change shape. Stove pipe joints differ from the other techniques in that they use rigid materials that cannot stretch. When drawn, their configuration relies on altering the shape of the patterns and their relative positions, to change the garment shape. Patternmakers can surely learn more in general from laces and stove pipe joints.

Conclusion

It is observed that most so-called non-wrinkle techniques that seek flexibility, actually use similar methods to create wrinkles. In pleats, laces and bellow joints, wrinkles are engineered into a specific shape. Laces and eyelets used the lace's tension to create pattern fits of different sizes. Stove pipe joints on the other hand change the pattern shape, and do not rely on wrinkles to change the garment shape. Patternmakers may take inspiration from these approaches to create patterns that change shape instead of relying on wrinkles.

17. Variable Darts

Experiment 64: **Variable structures**

Experiment 65: **Variable darts**

Experiment 66: **Exploring the properties of oblique cones**

Experiment 67: **Programming the interaction of variable darts**

Experiment 68: **Using variable structures to design garments**

Experiment 69: **Using oblique cones in variable darts**

Experiment 70: **The control points of a variable dart**

Experiment 71: **Different configurations of variable darts**

Aim

This group of eight experiments explores the properties of variable structures, namely patterns that can change in time to anticipate and adapt to the human body shape. While conventional garment patterns have a single static shape, variable structures are designed to morph into a variety of shapes. They in fact anticipate how body movement will change the pattern shape, and are designed to respond in a particular way. A major case in point is variable darts, which are designed to change shape in time according to body movement and to create different functions and aesthetics. The group of experiments exhaustively tests different configurations of the variable dart, particularly noting that geometric forms such as oblique cones are ideal for creating variable darts with different behaviours. Using control points to determine the size and shape of the dart, it is possible to explore ways that these points can be manipulated for different effects. The experiments also show how the addition of garment accessories such as belt loops, eyelets and elastic can generate variations in the variable dart.

Method

The first experiment offers several thought experiments that inspire the need for variable structures. The second describes the properties of the variable dart and the ability to control it to change shape in time. The third explores oblique cones, and the differences in geometric properties to right-angled cones. The fourth explores the interactive nature of variable darts and how they may be designed or "programmed" to exhibit specific behaviour. The fifth experiment offers hypothetical examples of how variable darts might be designed to enhance the garment's functional and aesthetic properties. The sixth explains how oblique cones can be used to make variable darts more responsive, while the seventh experiment explores the properties of the control point, which determines the shape of the dart. The final experiment describes how different configurations of variable darts can be used to create patterns with complex behaviours.

Analysis

These experiments, in exploring the properties of variable structures, offer new ways for patternmakers to build garments with diverse behaviours. Variable structures are designed to change in time, anticipating body movement and changing the garment in ingenious ways. The control points of a variable dart determine the shape of the dart, so that to alter the properties of these control points as well as putting the darts in different configurations, can change the garment's behaviour. The research explores accessories such as elastic or eyelets can also be used to change the responsiveness of variable darts, adding a new dimension to design as the patternmaker determines how the garment will look and change shape over time. In sum, the modern patternmaker should use variable structures to program the behaviour of the garment pattern.

Experiment 64: Variable Structures

Rationale

This thought experiment uses concepts from literature and mathematics to seek a "variable" patternmaking structure that can turn into multiple shapes in time, in contrast to conventional patterns that constitute a single shape in time.

Hypothesis

The experiment takes inspiration from concepts in literature and geometry in order to find a "variable structure".

Experimental Design

The first part explores concepts, seeking inspiration to build a pattern that changes shape in time to become multiple patterns. The second part attempts to build a variable structure for use in patternmaking.

Procedure

The experiment consists of two parts.

Part 1:

Generate illustrations inspired by Edwin A. Abbott's 1884 novel *Flatland: A Romance of Many Dimensions,* then compare his concepts with geometric properties related to the cross-sections of cones (Abbott 2010). This comprises diagrams 1 to 5.

Part 2:

Try to create a variable structure patternmakers can use to create multiple shapes over time. This comprises diagrams 5 and 6.

Results

Part 1:

At first it seems unlikely that it is possible to create a flat patternmaking structure that can be designed into different shapes in time. Fabric can be stretched to form different shapes, but the patternmaker has little control. The dilemma is similar to a situation in E. A. Abbott's fictional world of *Flatland* (2010), where everything is two-dimensional and the entire world is flat, so that its inhabitants cannot conceive of a third dimension (see figure 1, below). In *Flatland* (2010), three-dimensional beings can achieve seemingly impossible feats such as changing shape in time (see figure 2). This is achieved by moving a 3D object into different positions on the flat space. Inspired by this idea it seems plausible that some 3D shapes could create a wider variety of shapes than others, leading us to position a three-dimensional cone at different angles to create a variety of shapes (figure 3).

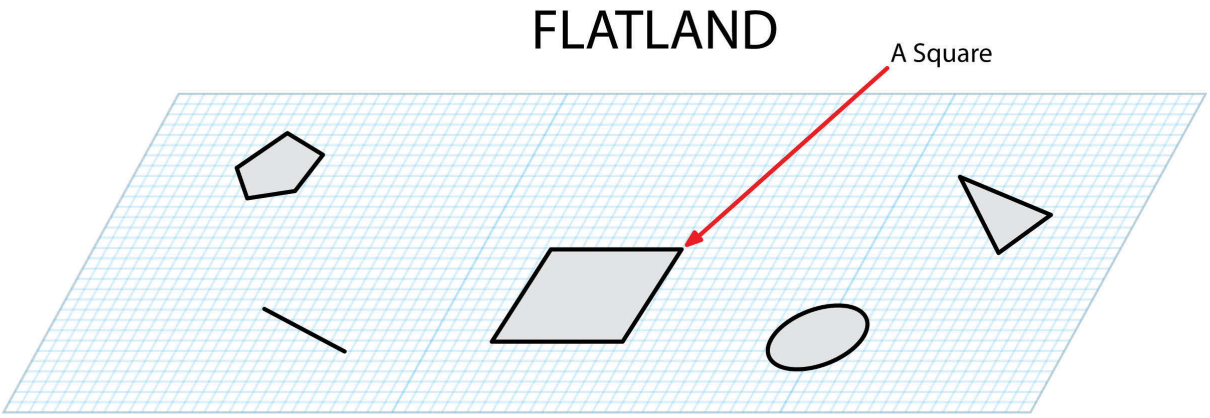


Figure 1: In the fictional world of *Flatland* the entire world is two-dimensional (2010 Abbott).

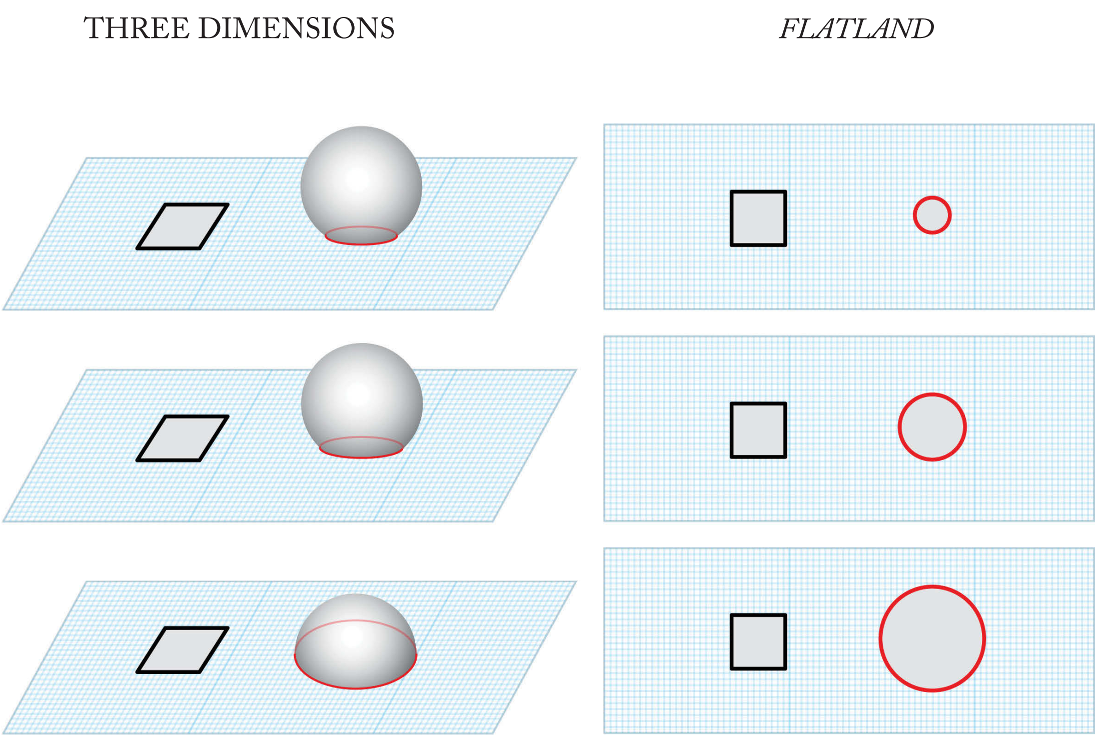


Figure 2: In *Flatland*, a three-dimensional form can change shape by moving its position (2010 Abbott).

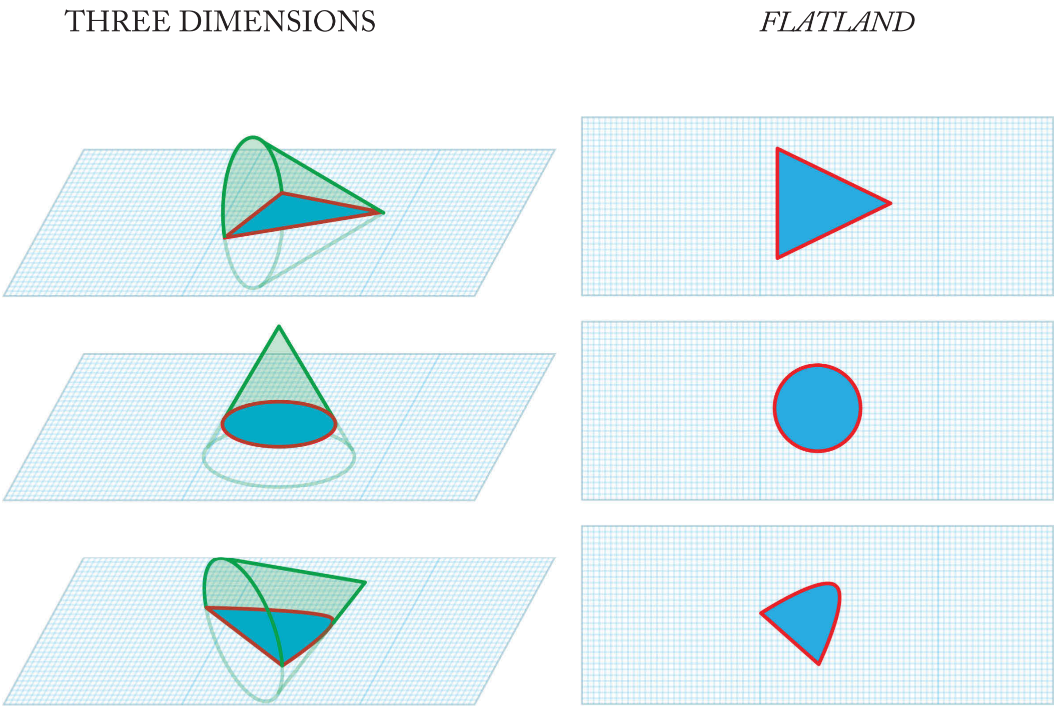


Figure 3: Inspired by the story of *Flatland* (2010 Abbott), different shapes are tested, that can change their shape over time.

Part 2:

After exploring the concept of *Flatland,* it became apparent that a three-dimensional shape could be flattened onto a flat surface at different angles to create a variety of shapes. By altering the angle of the 3D form, the pattern shape can be controlled. In patternmaking the most basic way of changing the shape of garment is a dart. Darts are static and do not change shape. *Flatland* inspires the concept of a "variable dart", a dart that can form multiple shapes over time (see figure 4). To control the shape of the variable dart the research would need a three-dimensional structure that can be folded flat in time to change the dart shape (see figures 5 and 6), creating a new way to control the shape of the variable dart over time.

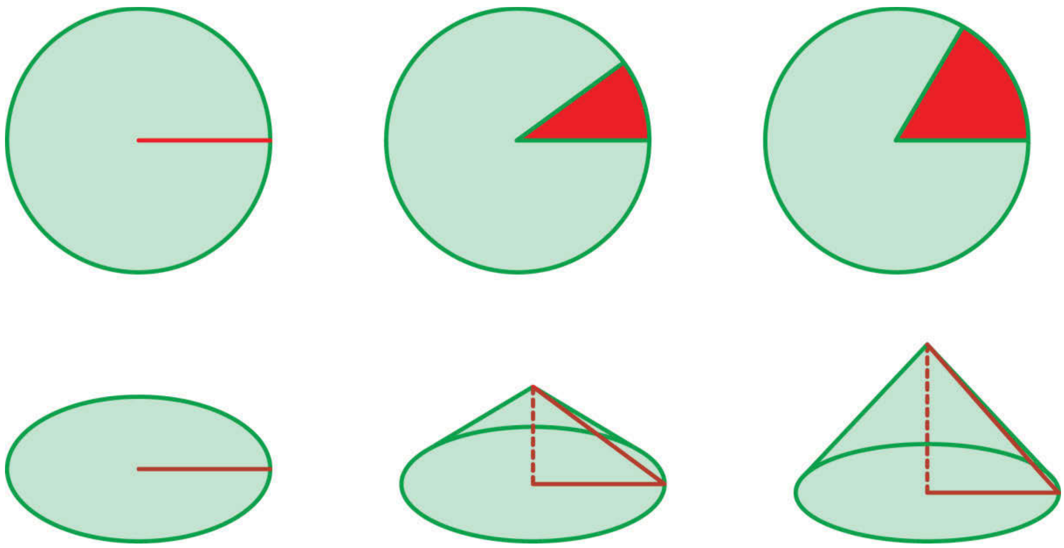


Figure 4: A “variable structure” is a pattern that can change shape over time.

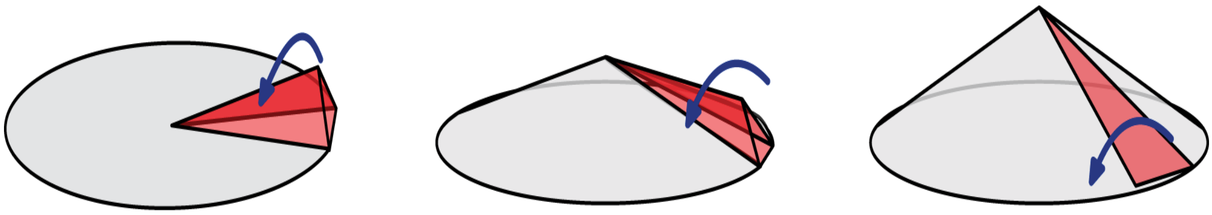


Figure 5: A variable dart can change the geometry of a garment by being in one shape when in three dimensions, and another when flattened.

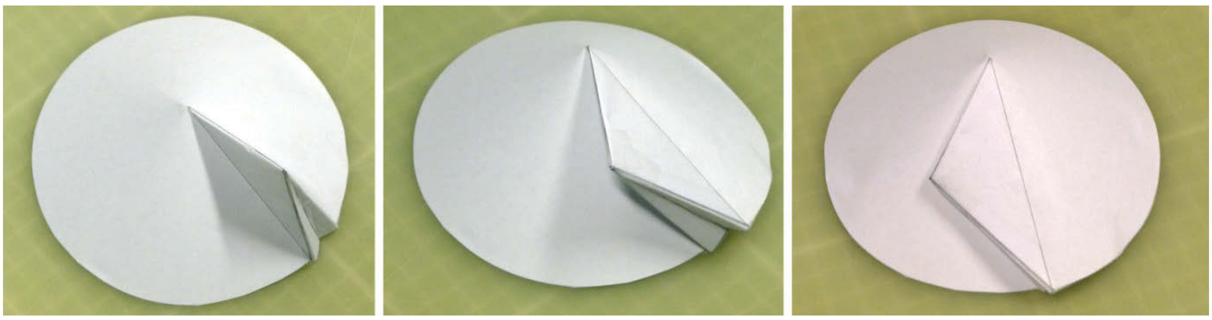


Figure 6: A paper model of **Figure 5.**

Conclusion

Inspired by the story and geometric principle of *Flatland* (Abbott 2010), it may well be possible to build a variable structure. This brings new factors into patternmaking, notably the ability to dynamically change the shapes of darts. Conventional garment patterns are static structures while variable structures are dynamic. A static structure is a single state, while a dynamic structure must consider how the pattern will change over time.

Experiment 65: Variable Darts

Rationale

This experiment explores the properties of "variable darts", namely those that can form multiple shapes over time. A conventional dart is fixed in a single static position while a variable dart can become multiple sizes in time. The ability to control the dart shape adds a new dimension to the pattern design, allowing patterns of a static shape to dynamically change.

Hypothesis

The research anticipates the creation of a dart that changes shape in time, whereby the size of it is controlled by a control point.

Experimental Design

In order to create a dart that can change shape in time, a three-dimensional cone structure has to be mounted on top of the dart. First, mount a right-angled cone on the dart, and when the cone tip is pulled with different tensions, it changes the dart's dimensions. In effect, the cone tip forms a control point to manipulate the variable dart's shape. The second iteration tests the use of an oblique cone as the control point. These cone types are tested on darts of diamond and triangular shapes.

Procedure

<u>Part</u> 1:

The first iteration places a right-angle cone on the tip of a variable dart to control its shape. The variable dart is tested on diamond-shaped and triangular-shaped darts.

The diamond-shaped dart

Mount a right angled cone on top of the fabric. The base of the cone should create a diamond-shaped dart (at this stage it should be very round in shape). Sew the cone onto the fabric and cut out the fabric on the inside of the cone. This creates the variable dart.

Model 1: Start with the right cone in the initial position.

Model 2: Pull the tip of the cone to the right. This should change the shape of the dart, which will change the shape of the pattern's surface.

Model 3: Pull the tip of the cone to the extreme right and flatten the cone on the pattern's surface.

The triangular-shaped dart

Start with a cone with a triangular dart on its side. Mount a right angle cone on the pattern. It may be difficult to mount a rounded right cone on the pattern so that the pattern can be a right-angled triangular pyramid. Sew the pyramid to the pattern and cut out the fabric on the base of the pyramid. This creates the variable dart.

Model 4: Start with the right cone in the initial position.

Model 5: Pull the tip of the cone to the left. This should change the shape of the dart, which will change the shape of the cone surface.

Model 6: Pull the cone tip to the extreme left and flatten the cone on the pattern surface.

<u>Part 2</u>:

The second iteration places an oblique cone on the tip of a variable dart to control its shape. The variable dart is tested on diamond-shaped and triangular-shaped darts.

The diamond-shaped dart

Mount an oblique cone that tilts to the right on top of the fabric. The base of the cone should create a diamond-shaped dart (at this stage it should be very round in shape). Sew the cone onto the fabric and cut out the fabric on the inside of the cone. This creates the variable dart.

Model 7: Start with the right cone in the initial position.

Model 8: Pull the tip of the cone to the right. This should change the shape of the dart, which will change the shape of the pattern's surface.

Model 9: Pull the tip of the cone to the extreme right and flatten the cone on the pattern's surface.

The triangular-shaped dart

Start with a cone with a triangular dart on its side. Mount an oblique cone that tilts to the left on the pattern. It may be difficult to mount a rounded oblique cone on the pattern so that the pattern can be an oblique triangular pyramid. Sew the pyramid to the pattern and cut out the fabric on the base of the pyramid. This creates the variable dart.

Model 10: Start with the right cone in the initial position.

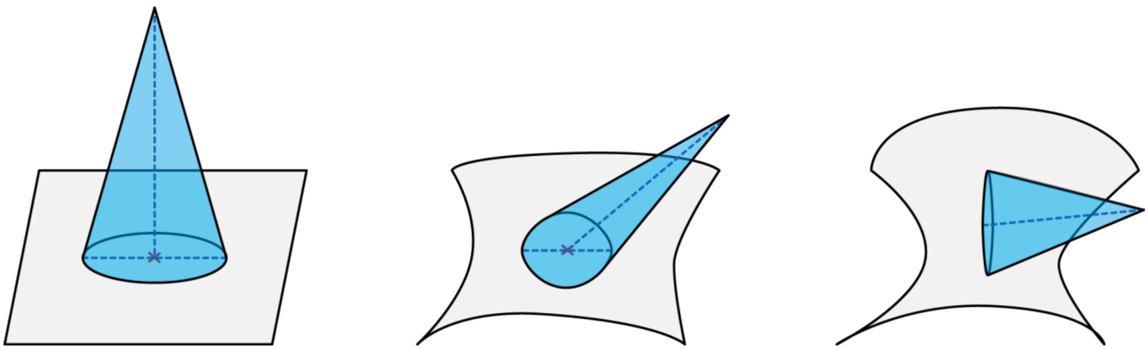
Model 11: Pull the tip of the cone to the left. This should change the shape of the dart, which will change the shape of the cone surface.

Model 12: Pull the cone tip to the extreme left and flatten the cone on the pattern's surface.

Results

Part 1: Right-angled cones

The diamond-shaped dart



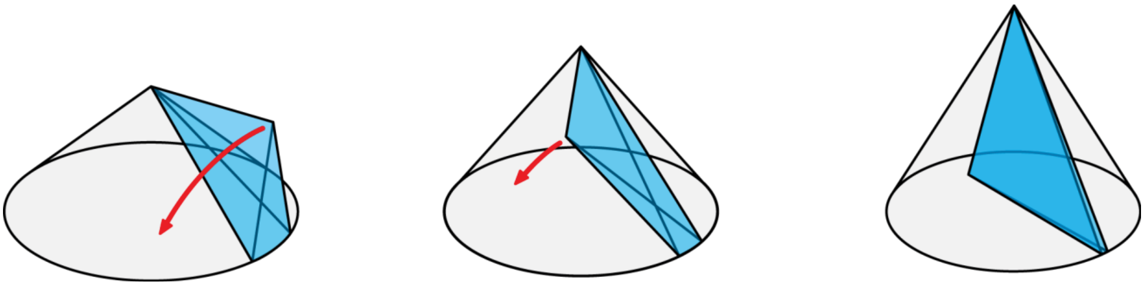
Model 1: Open.	Model 2: Transition.	Model 3: Closed.

Figure 1: Right cone folding over.

Model 1: Open.	Model 2: Transition.	Model 3: Closed.

Figure 2: Paper models of **Figure 1.**

The triangular-shaped dart



Model 4: Open. | Model 5: Transition. | Model 6: Closed.

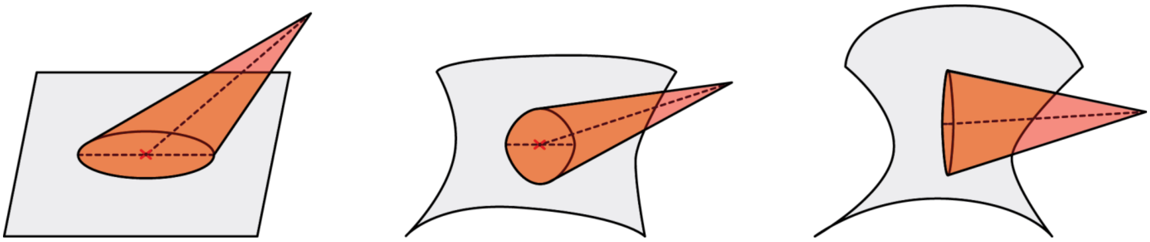
Figure 3: Experimenting with right cones to create a variable dart.

Model 4: Open. | Model 5: Transition. | Model 6: Closed.

Figure 4: Paper models of **Figure 3.**

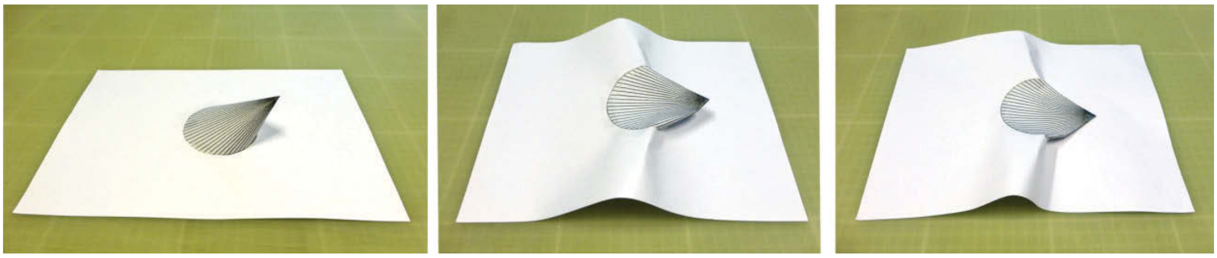
Part 2: Oblique cones

The diamond-shaped dart



Model 7: Open. | Model 8: Transition. | Model 9: Closed.

Figure 5: Oblique cone folding over.



Model 7: Open. | Model 8: Transition. | Model 9: Closed.

Figure 6: Paper models of **Figure 5.**

The triangular-shaped dart

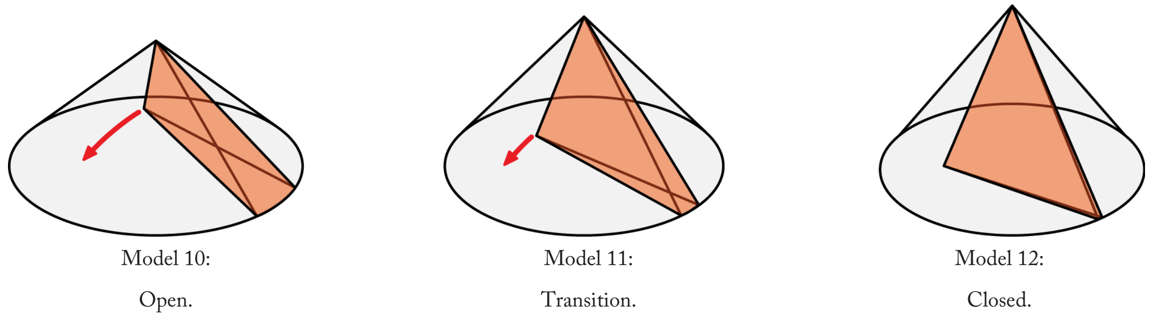


Figure 7: Experimenting with asymmetrical cones to create a variable dart. Asymmetrical cones are flatter and create a wide variety of shapes.

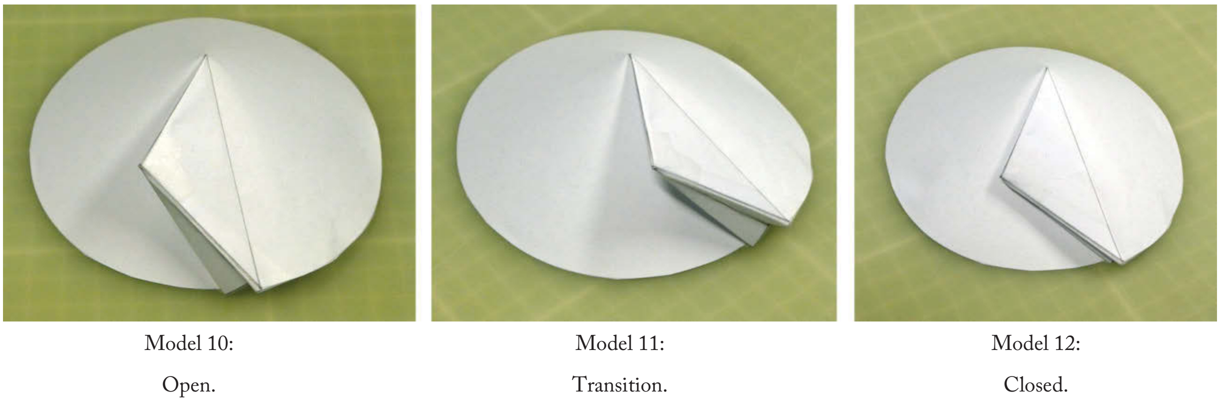


Figure 8: Paper models of **Figure 7.**

Observations

The variable darts on the diamond dart allow the pattern to transform from a flat pattern into a more hyperbolic shape. The variable dart on the triangular-shaped dart allows the cone pattern to become more spherical in shape. It is observed that the oblique cones, due to their tilted angle, required far less effort to flatten.

Conclusion

It is eminently possible to create a variable dart that changes shape over time. The cone tip and the tension at which the cone is maintained controls the shape of the variable dart. The research created two versions of the variable dart. One used a right-angled cone while the other used an oblique cone. The oblique cone required far less effort to manipulate due its tilted shape. It also required less movement to control, making it a much more effective design for the variable dart. It is observed that variable darts also changed the patterns in two different designs. One controlled the cone angle of a dart, making it more spherical, while the other (diamond-shaped) dart made the pattern more hyperbolic. In sum, variable darts should be designed to modify patterns in a wide variety of ways.

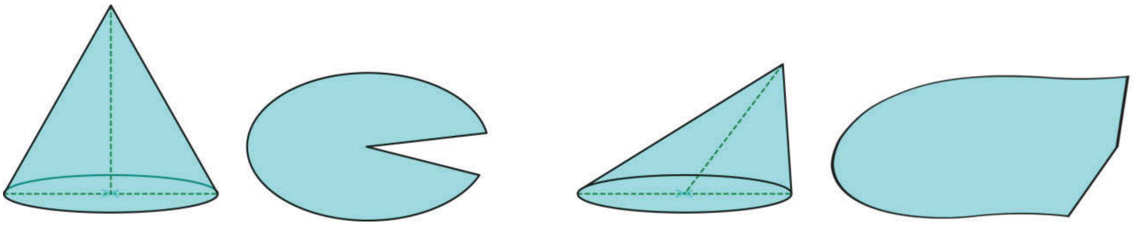
Experiment 66: Exploring the Properties of Oblique Cones

Rationale

This experiment explores the properties of oblique cones. Patternmaking structures such as darts tend to use right-angled cones. The geometric properties of oblique cones are different to right cones (see figures 1 and 2). The former are not commonly used by patternmakers, so that the research should explore their properties in greater detail. The experiment shows diverse ways patternmakers can generate oblique cones.

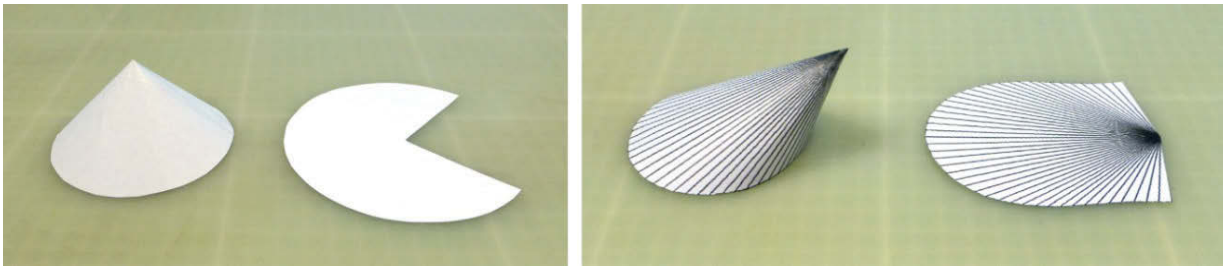
Hypothesis

The research anticipates that oblique cones have different properties to right-angled ones. There should be several ways to generate patterns, using both computer programs and manual drafting techniques.



Right Cone Oblique Cone

Figure 1: Right cones are different from oblique cones.



Right Cone Oblique Cone

Figure 2: Paper models of **Figure 1.**

Experimental Design

The experiment shows three ways patternmakers can generate patterns that are oblique cones. The first iteration creates an oblique cone by cutting a cross-section of a right cone. The second uses computer software called *Conical Transformers CONET* to generate oblique cones (Harness 2006). The third generates oblique cones by moving the cone's apex point.

Procedure

Part 1:

The first iteration makes an oblique cone by cutting the top off a right cone. The cut must be a flat plane that intersects with the cone. By tilting the cone at different angles it is possible to create different shapes of oblique cone.

Model 1: Create a right-angled cone from a flat piece of paper. Tilt the cone at an angle. Cut a flat plane through the cone to create an oblique cone. This process is easy to do as a geometric transformation, but more difficult to achieve with paper models.

Part 2:

Use the program *Conical Transformers CONET* (Harness 2006) to create oblique cones in three dimensions (see figure 3, below). The software creates a cone in 3D, following which the cone tip is moved to make the cone more oblique. The software then flattens the cone into a flat pattern.

Model 2: Create an oblique cone with an apex point that is off-centred. Use the *Conical Transformers CONET* software (Harness 2006) to observe the flat pattern of the oblique cone.

Model 3: Create another oblique cone with the apex moved further away from the centre of the pattern.

Model 4: Create another oblique cone with the apex moved further from the pattern's centre.

Model 5: Create another oblique cone with the apex moved further from the pattern's centre.

Model 6: Create another oblique cone with the apex moved further from the pattern's centre.

Model 7: Create another oblique cone with the apex moved further from the pattern's centre.

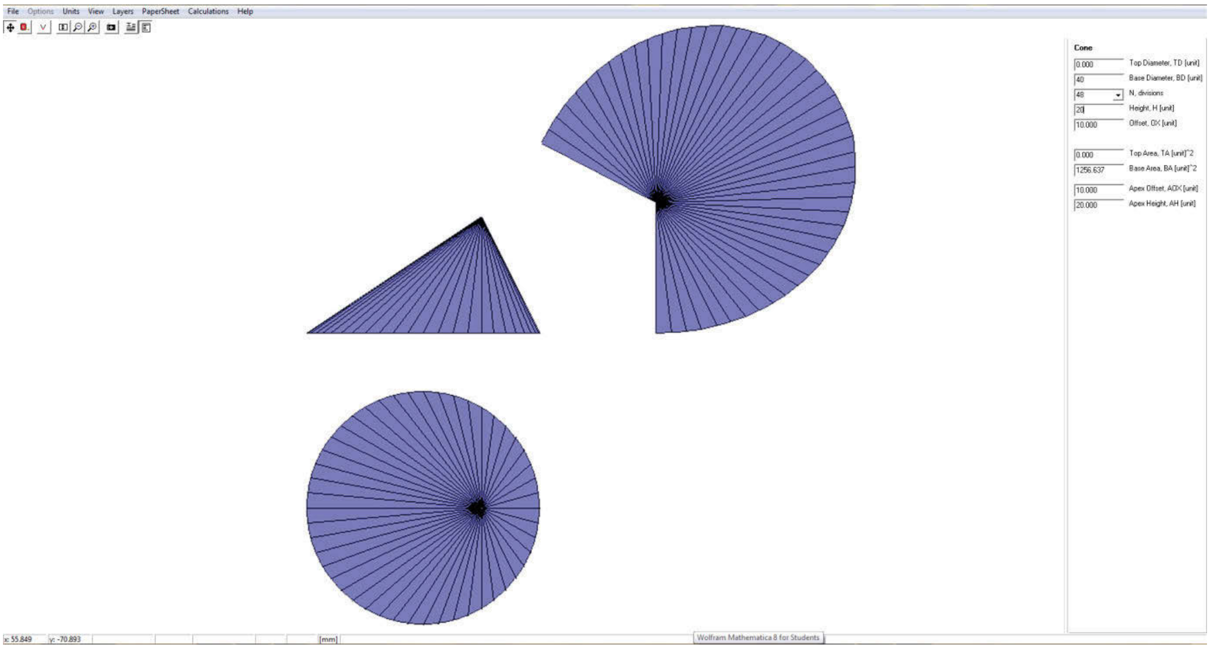
Observe the patterns created by the cones.

Part 3:

The third iteration constructs an oblique cone by moving the location of the apex point of the dart. Moving the apex away from the centre of the cone tilts the pattern and turns it into an oblique cone.

Model 8: Create two patterns for a right-angled cone. Construct one as a flat pattern and the second in three-dimensions (see figures 6 and 7).

Model 9: Create two identical copies of model 8. Move the location of the apex away from the cone's centre. Construct one of the patterns in 3D and leave the other as a flat pattern (see figures 6 and 7).

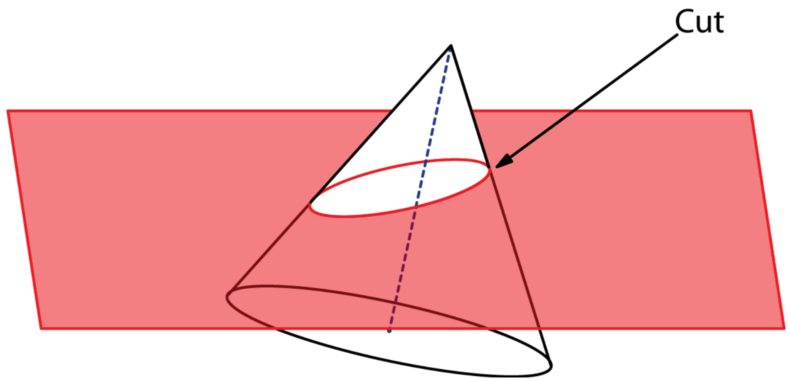


Model 2

Figure 3: Computer software such as *Conical Transformers CONET* (Harness 2006) creates flat patterns for oblique cones.

Results

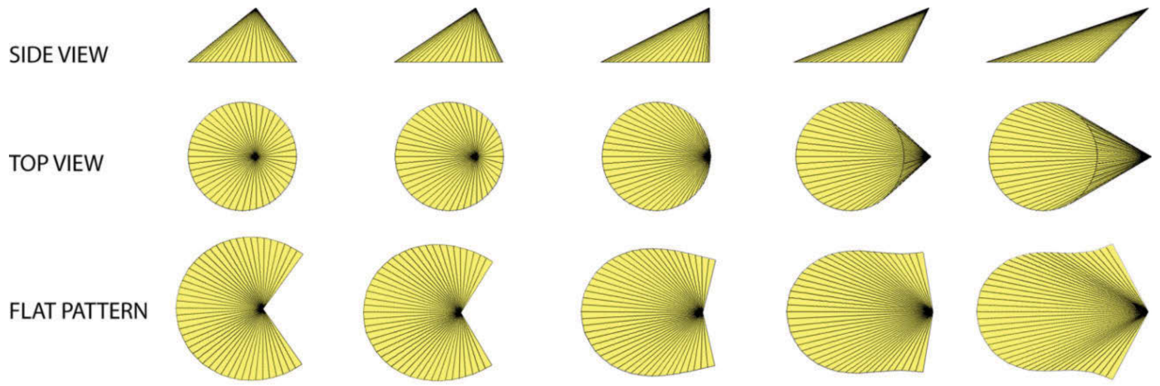
Part 1:



Model 1

Figure 4: Oblique cones can be created by cutting the top off right cones at different angles.

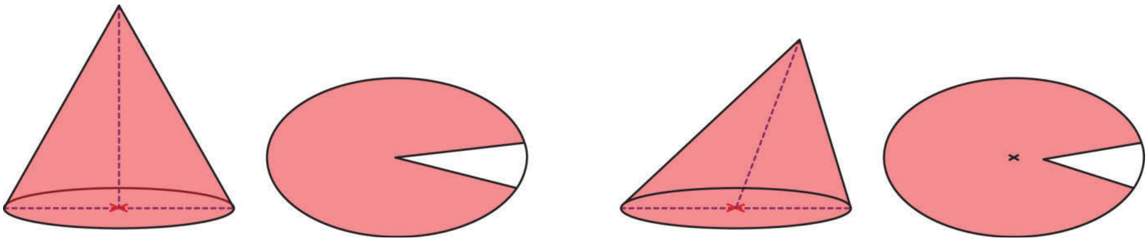
Part 2:



Model 3 Model 4 Model 5 Model 6 Model 7

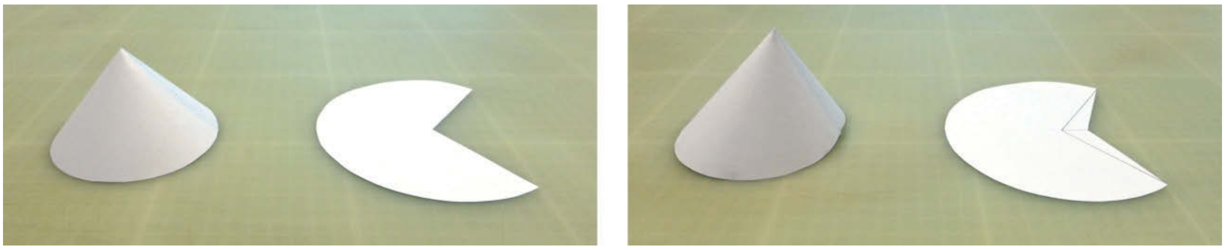
Figure 5: Oblique cones create flat patterns with very different shapes to right cones.

Part 3:



Model 8 Model 9

Figure 6: A quick way to create oblique cones without using computers is to move the location of the cone tip away from the centre of the pattern.



Model 8 Model 9

Figure 7: Paper models of **Figure 6.**

Conclusion

There are multiple ways for patternmakers to draft oblique cones. Computer programs are accurate and effective for creating complex oblique cones, but are a little more time-consuming and take the patternmaker away from the paper pattern. For less complex oblique cones, moving the cone's apex is a quick and convenient way to create oblique cones. Taking a right-angled cone and cutting it at an angle can quickly generate these as well.

Experiment 67: Programming the Interaction of Variable Darts

Rationale

This experiment explores the possibilities of programming variable darts to perform different functions. The shape of a variable dart is controlled by the position of its control point. By placing variable darts in different configurations it is possible to design them to function in different ways, allowing the garment to be programmed to make it behave in a certain way.

Hypothesis

The research anticipates that body movement can manipulate the control points of a variable dart and alter the garment's shape. The interaction of the body and control points allows the patternmaker to program a variable dart with "behaviour".

Experimental Design

The experiment explores the strategies used to control the behaviours of variable darts. The first iteration investigates the properties of variable darts, examining possible different states and the ways they can be controlled. The second iteration tests ways variable darts can change the garment's pattern, comparing the placement of a single variable dart to placement of many. It explores what happens when the control points of variable darts are placed on those of others, allowing the movement of a single control point to change the shape of multiple variable darts.

Procedure

Part 1:

Variable states of a variable dart

Start with a cone and place a triangular-shaped variable dart on its side. Attach a cord to the tip of the control point so that the dart can be easily pulled.

Model 1: Start with the control point upright with the dart in an open position.

Model 2: Pull on the control point so that the variable dart partially closes.

Model 3: Pull on the control point so that the variable dart fully closes.

The input and output of a variable dart

Create a cylindrical pattern for a sleeve. Place a diamond-shaped variable dart on the top of the bend joint. Attach a cord to the control point of the variable dart.

Model 4: Start with the sleeve pattern and do not pull on the control point of the variable dart.

Model 5: Pull on the control pattern of the variable dart. Observe how moving the control point changes the shape of the variable dart.

Model 6: Observe how a variable dart has an input that controls the shape of the dart and an output that changes the shape of the pattern.

Part 2:

Placing multiple variable darts on a pattern

Model 7: Create the garment pattern for a top with a sleeve and place a variable dart on the top shoulder. Illustrate in red the shape of the garment with the arm by the side of the wearer. Superimpose in blue an image of the garment with their arm raised. Make observations of how the variable darts affect the pattern.

Model 8: Create the garment pattern for a top with a sleeve, and place a variable dart on the top shoulder. Place a second variable dart under the arm of the sleeve. Illustrate in red the shape of the garment with the arm by the side of the wearer. Superimpose in blue an image of the garment with their arm raised. Make observations of how the variable darts affect the pattern.

Attaching the control points of multiple darts together

Model 9: Start with a flat piece of fabric. Place a variable dart (in green) to the centre and attach a cord to the dart's control point. Mount another variable dart (in orange) to the left of the first dart and place its control point onto the side of the green dart. Illustrate this diagram when the darts are open and the control point is not being pulled. Next, illustrate the diagram after the control point has been pulled.

Model 10: Start with a flat piece of fabric. Place a variable dart (in green) to the centre and attach a cord to the dart's control point. Mount a variable dart (in orange) to the left of the first dart and place its control point onto the side of the green dart. Mount another variable dart (in black) on the left side of the green dart and attach the control point to the side of the green dart. Illustrate this diagram when the darts are open and the control point is not being pulled. Then illustrate the diagram after the control point has been pulled.

Model 11: Start with a flat piece of fabric. Place a variable dart (in green) to the centre and attach a cord to the dart's control point. Mount a variable dart (in orange) to the left of the first dart and place its control point onto the side of the green dart. Mount another variable dart on the right side of the green. Pull closed the control point of this dart, then attach it to the control point of the green dart. Illustrate this diagram when the darts are open and the control point is not being pulled. Then illustrate the diagram after the control point has been pulled.

Results

Part 1:

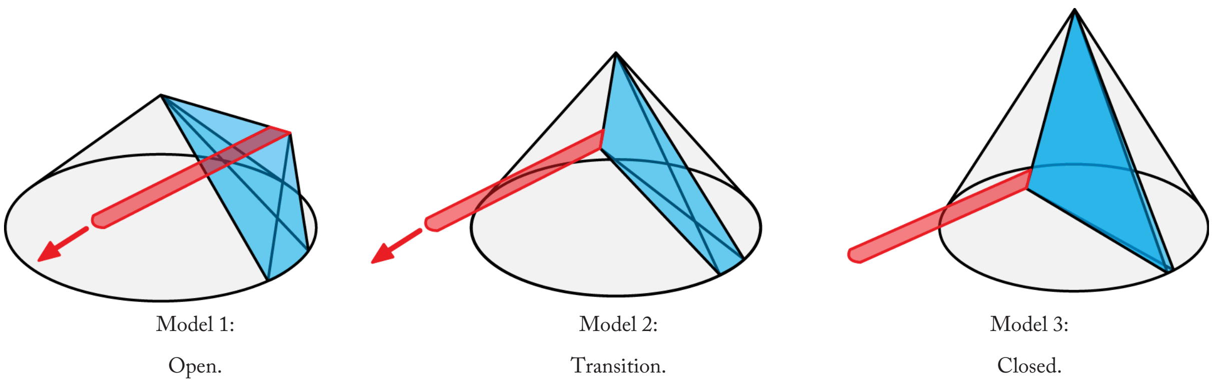
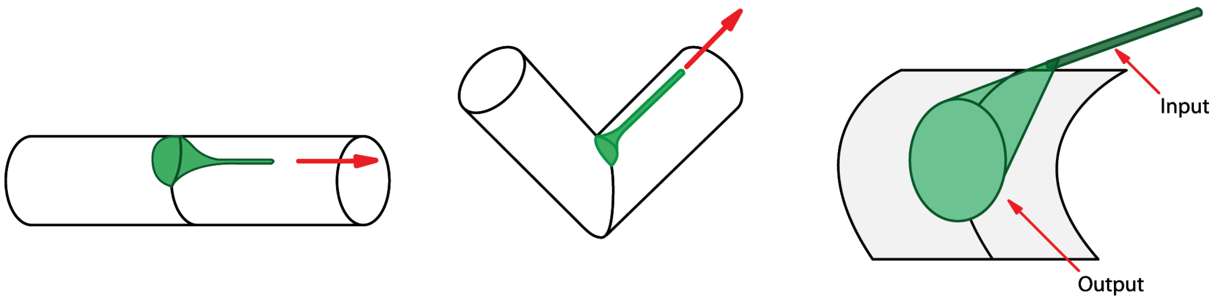


Figure 1: The way that variable darts can be controlled is similar to a switch.

A variable dart is like a light switch that can be dimmed or turned on and off, ie: it controls input and output. In this case, the dart is open or closed (models 1 and 3). Between these two states, the dart can transition (model 2).



Model 4:

The body movement is the input.

Model 5:

The change of the variable dart is the output.

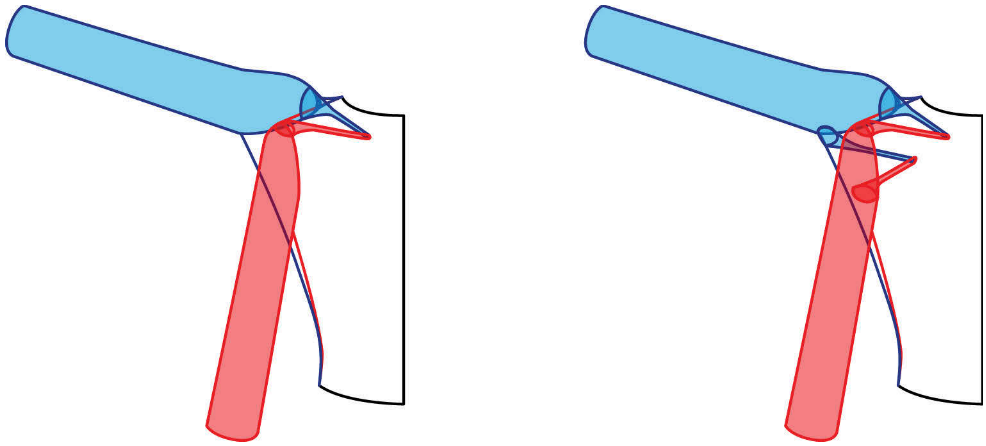
Model 6:

The variable dart has and input and output.

Figure 2: A variable dart is like a switch that controls the dart's input and output.

Variable darts, when placed on the body, have an input and an output. In models 4 and 5, body movement causes the variable dart to change shape. It is controlled by moving the control point of the garment (see model 6). This can be termed the "input" of the garment. Moving the control point causes the garment to change shape. This is termed the "output" of the variable dart. Hence, by controlling the input the patternmaker can control the output. It is thereby possible to place the input of variable darts on moving parts of the body that will continually trigger the variable dart.

Part 2:

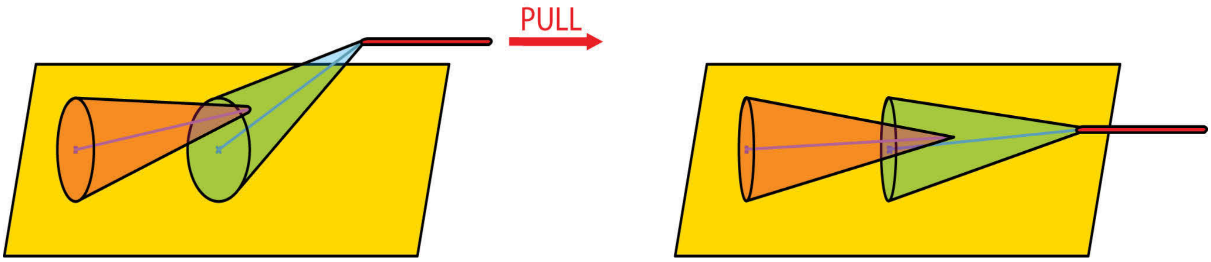


Model 7: Single variable dart in two different positions (blue and red).

Model 8: Multiple variable darts in two different positions (blue and red).

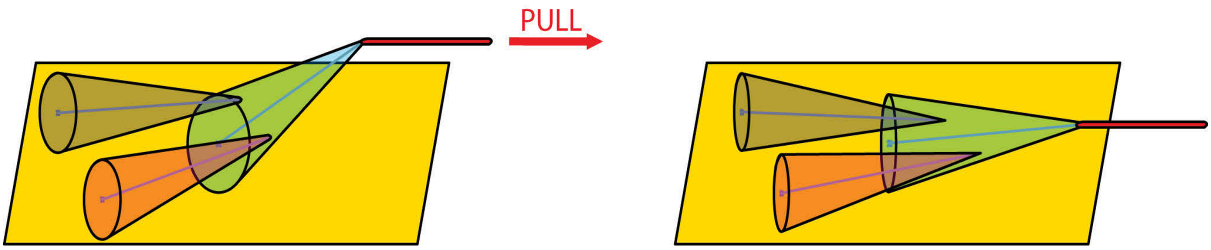
Figure 3: Different configurations of variable darts can change how the garment changes when the body moves.

In model 7 there is a single variable dart that moves with the arm's position and changes the dart's shape on top of the shoulder. In model 8 there are two variable darts. This means that when the arm is raised, both the dart on the top of the shoulder and under the arm change shape. Using multiple variable darts allows a single body movement to change the shape of multiple parts of the garment.



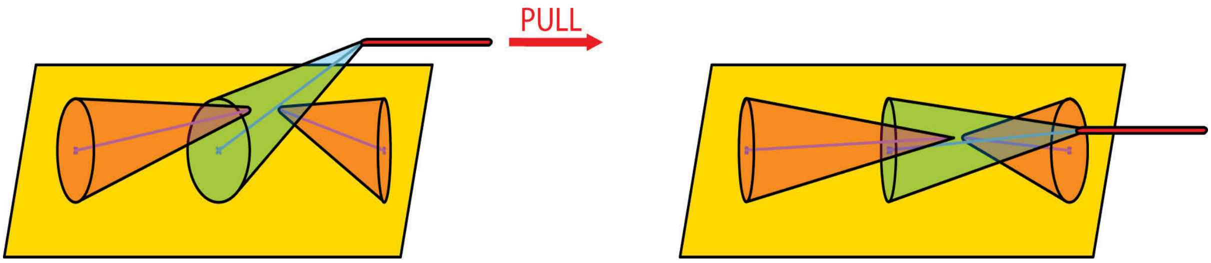
Model 9

Figure 4: The control point of the orange variable dart is placed on the control point of the green dart. A single pull of the control point changes the shape of two variable darts.



Model 10

Figure 5: The control point of two variable darts is placed on the control point of the green dart. A single pull of the control point changes the shape of two variable darts.



Model 11

Figure 6: The control point of two variable darts is placed on the control point of the green dart. The variable dart on the left is opened and the one on the left is closed. A single pull of the control point causes the dart on the left to close while the one on the right opens.

In model 9, joining a variable dart to the control point of another variable dart, is a way to control several variable darts with one movement. In model 10, two darts can be controlled by attaching them to the control point of a single variable dart. In this configuration, both close when the main dart is closed. In model 11, two variable darts can be attached to the control point of a variable dart. This time, closing the main variable dart causes one dart to open and the other to close. There are many different ways variable darts can be joined to create more complex behaviour.

Conclusion

The experiment offers many configurations of variable darts, placed to achieve different effects. It can in fact harness a single body movement to control the shape of multiple variable darts. In sum, it can use diverse configurations of variable darts to design and program different behaviours into the garments.

Experiment 68: Using Variable Structures to Design Garments

Rationale

This experiment explores different scenarios where variable darts can be integrated into a design to enhance a garment. Beyond conventional fashion garments with their static fixed forms, variable structures can create new shapes to enhance effect and function.

Hypothesis

The research anticipates new aesthetic effects and functions through the use of variable darts.

Experimental Design

The experiment presents three scenarios where variable darts can be used in garment design. The first involves adding a variable dart to the sleeve of a pattern to improve fit as the body moves. The second features a skirt designed to protect the wearer's modesty in a sitting position. The third iteration is a skirt that changes shape depending on walking speed.

Procedure

The experiment has three parts.

Part 1:

The first garment uses variable darts to improve fit as the body moves.

Create a top with sleeves. Mount a variable dart on the top of the shoulder. Place the control point of the variable dart at the centre of the garment's front. Illustrate the garment in red, with the arm resting by the garment's side. Superimpose in blue an image of an arm raised in the air.

Part 2:

The second iteration is a skirt designed to protect the wearer's modesty. If the wearer in a sitting position spreads their legs, the garment is designed to tighten the front so that it is not possible to look up the skirt (see figure 2, below). Variable darts are attached inside the skirt so that if the legs are pulled apart, the same motion will pull the skirt front between the wearer's legs. In this design, two variable darts are attached to the skirt front between the legs. The darts are connected to long cords that extend the length of the control points. Two loops are sewn inside the back of the skirt, and the control points are run through these loops. The control points are then attached to the side seams of the skirt. When the wearer moves their legs to the sides, they pull on the control point which tightens the variable darts on the garment's front.

Part 3:

The third iteration is a skirt designed to raise its hem depending on the wearer's walking speed. Raising the hem clearly makes it easier to walk quickly or run. The range of motion of a walker and a runner are very different (see figure 3), such that the distance between body landmarks increases depending on pace. When a person walks, their range of body movement is less than when running. The design places variable darts into the skirt hem. In effect, the control points of the variable darts are put on parts of the garment that move a further distance when the wearer moves faster. When the wearer runs, their movement pulls on the control points of the variable dart and this raises the hem height. Similarly, when the wearer slows down, the hem lowers.

Results

Part 1:

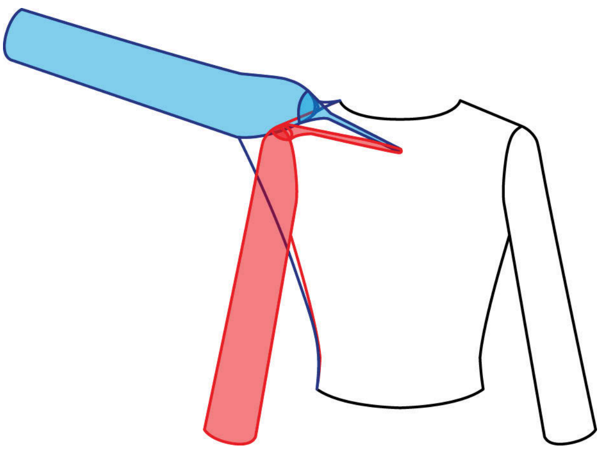


Figure 1: A garment built so that there is a variable dart on only one side of the garment. This means the garment will change shape in one way if the left arm is moved and a different way when the right arm is moved.

Part 2:

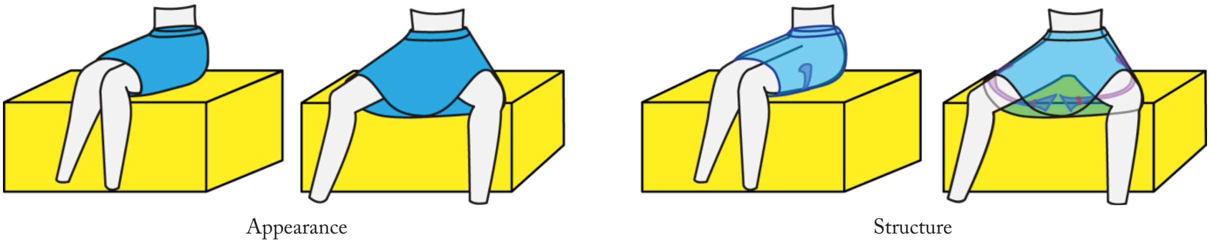


Figure 2: This garment changes shape to protect the modesty of the wearer when they sit down by pulling the skirt between the legs.

Part 3:

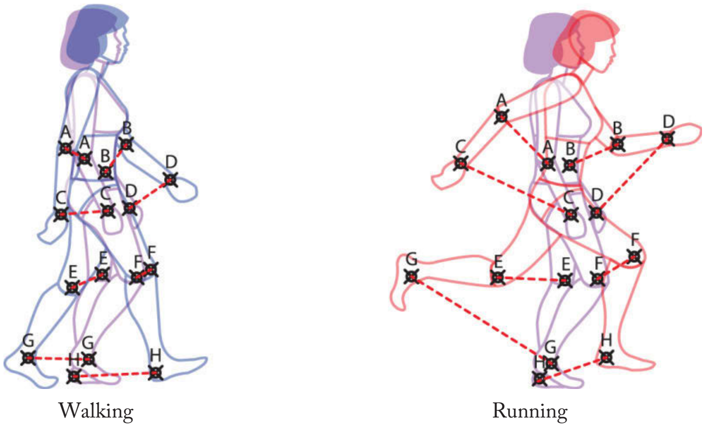


Figure 3: The range of motion is greater when running than it is when walking.

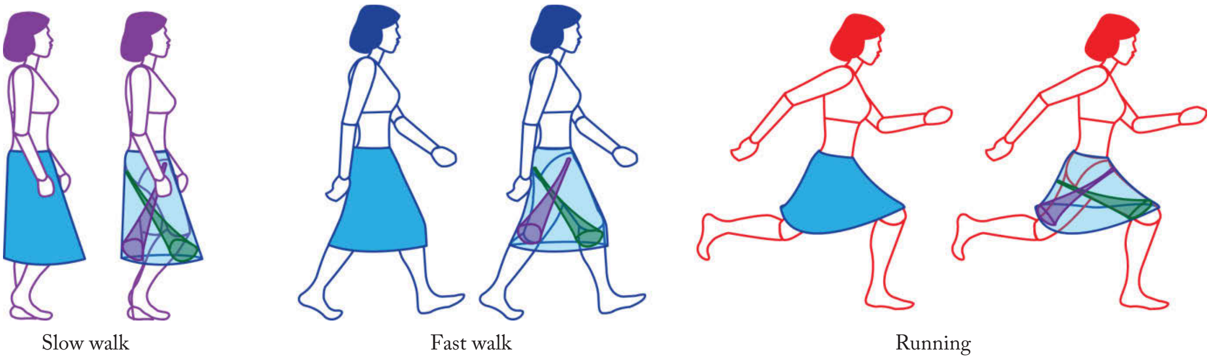


Figure 4: This garment maintains the shape when the wearer is walking, but as soon as they start to run the variable darts pull up the hem to make movement easier.

Conclusion

The experiment shows ways that variable darts can be used when designing garments. The first example changes the garment fit and enhances the wearer's comfort. The second uses a variable dart to intelligently design the skirt. Such a skirt protects the wearer's modesty and delivers an aesthetic function. The third garment performs a functional purpose by changing shape according to the pace of movement.

Experiment 69: Using Oblique Cones in Variable Darts

Rationale

This experiment explores the use of oblique cones as variable darts. In patternmaking, structures such as darts change the curvature of the fabric in a single shape. Variable darts can be adjusted into multiple shapes. Oblique cones have different properties to right-angled cones, and these have advantages when creating variable darts.

Hypothesis

The research points to the unique properties of oblique cones to create more effective variable darts.

Experimental Design

The experiment makes observations about the properties of variable darts. Where right-angle cones have a tip that points vertically and is directly above the base, oblique cones have a tip tilted at an angle and not centred over the base. The latter has advantages when creating oblique cones.

Procedure

Start with a flat piece of fabric and mount an oblique cone tilted in the centre at an angle. The base of the oblique cone should make a diamond-shaped dart (which is round in this position). Attach a cord to the tip of the oblique cone to make it easier to pull.

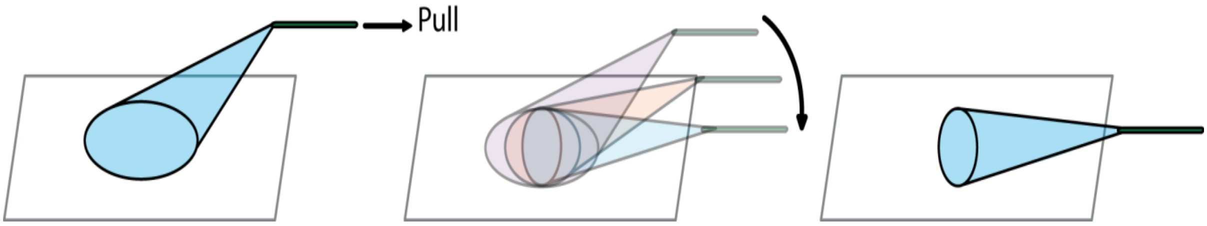
Model 1: Leave the variable dart in an open position.

Model 2: Pull the cord on the variable dart until the shape of the dart is between open and closed positions.

Model 3: Pull the cord to fully flatten the variable dart and close it.

Results

Part 1:



Model 1: Open. | Model 2: Transition. | Model 3: Closed.

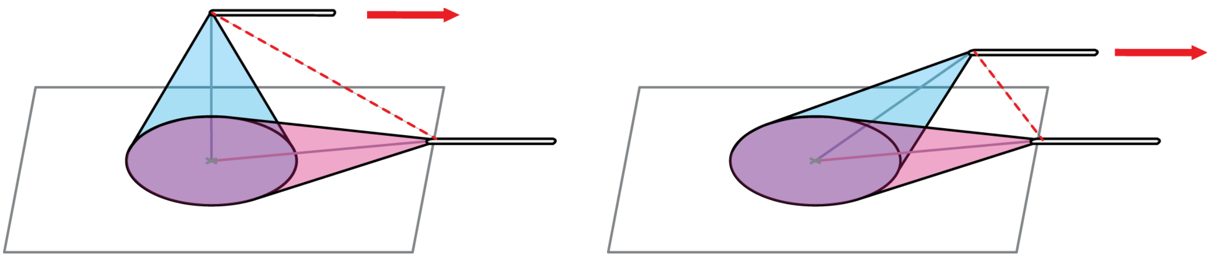
Figure 1: Oblique cones are ideal for use with variable darts.

Model 1: Open. | Model 2: Transition. | Model 3: Closed.

Figure 2: Fabric models of **Figure 1.**

Observations

Oblique cones are very effective as variable darts. Their angle tilt makes them sit closer to the shape of the pattern they are on. Their tilt also means that they need to be pulled a shorter distance to close the variable dart (see figure 2).



Right cone | Oblique cone

Figure 3: Oblique cones need to be pulled a shorter distance (red line) to close the variable dart.

Conclusion

The experiment demonstrates how oblique cones are effective as variable darts. Their tilted shape makes them sit closer to the surface of the fabric. They are also able to be pulled a shorter distance to close the variable dart as compared to a right-angled cone, making them easier to control.

Experiment 70: The Control Points of a Variable Dart

Rationale and Hypothesis

This experiment explores how the manipulation of control points of variable darts can modify the dart's behaviour. Each variable dart has a control point that controls its shape (see figure 1, below). It examines ways that the interaction of variable darts can be modified to achieve different effects on the garment.

Experimental Design

The control point is the part of a variable dart that can be moved to change the dart's shape, giving the garment a different fit. There are many ways in which the control point can move.

The first part of the experiment places elastic on the control point to control the rate at which the garment moves. The second part shows how strategically placing the control point in different positions can change the interaction of the variable dart, and the third part looks at the relationship between different body landmarks while a person is walking.

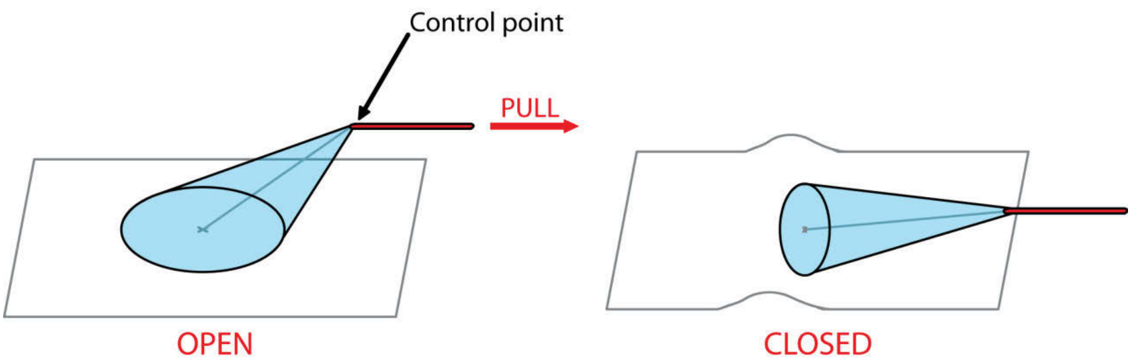


Figure 1: The control point of a variable dart can be manipulated to change the dart's shape.

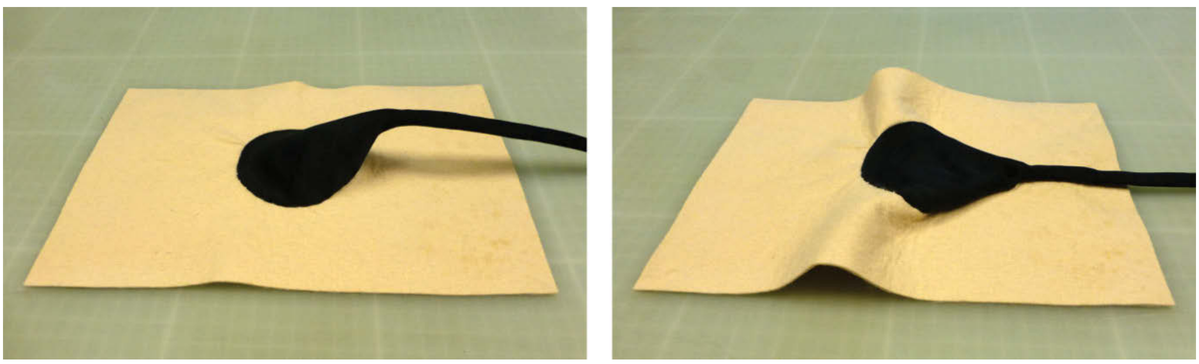


Figure 2: Fabric model of **Figure 1.**

Procedure

The experiment has three parts.

Part 1:

The first iteration explores how the properties of variable darts can be modified by attaching elastic to them. All these iterations begin with a variable dart with an oblique cone mounted on a flat piece of fabric.

Model 1: Start with the variable dart. Attach a piece of elastic to its control point.

Model 2: Start with the variable dart. Attach a rigid fabric cord to its control point. Attach a piece of elastic, from the control point to part of the garment to the left side of the variable dart.

Model 3: Start with the variable dart. Attach a rigid fabric cord to its control point. Attach a piece of elastic, from the control point to part of the garment to the left of the variable dart. Then attach another piece of elastic from the control point to the right side of the variable dart.

Part 2:

The second iteration shows how different body landmarks move in different relationships to each other. This is useful when deciding where to place the control points of variable structures. The experiment starts with a model wearing a blouse garment with a sleeve. The model stands with their arms by their sides (shaded in purple). They raise their arms to 45° to the torso (shaded in red), then raise their arms above their head (shaded in blue). Record the positions of these movements. The patternmaker then places as a body landmark an unmoving "anchor point". Following this they place a body landmark on a body part that will move. By choosing the location of the anchor points and body landmarks, it creates different ranges of motion. These can be used to control the behaviour of variable structures.

Model 4: Place the anchor point on the lower left of the torso, and place the body landmark on the outer edge of the sleeve. Draw lines from the body landmark to the anchor point to show how much the distance between the two changes over time.

Model 5: Place the anchor point on the upper left back of the torso, and place the body landmark on the inner edge of the sleeve. Draw lines from the body landmark to the anchor point to show how much the distance between the two changes over time.

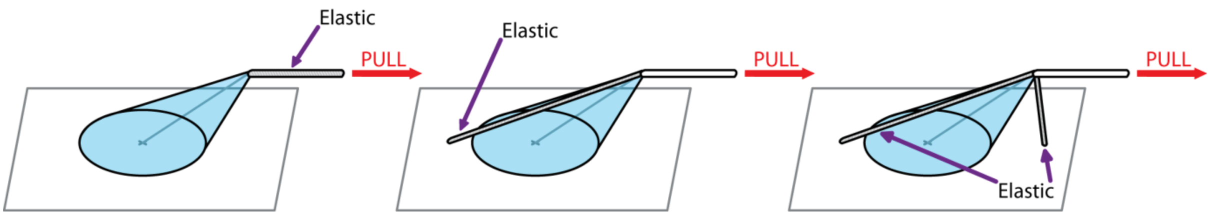
Part 3:

The third iteration, in analysing the poses of a person walking, observes how different body landmarks move over time. It is noted that some body parts move greater distances from each other.

Model 6: This iteration places body landmarks on the elbows, wrists, knees and ankles of a person walking, comparing the different distances that these body landmarks travel in that activity.

Results

Part 1:



Model 1:
Variable dart with elastic.

Model 2:
Variable dart with elastic.

Model 3:
Variable dart with multiple pieces of elastic.

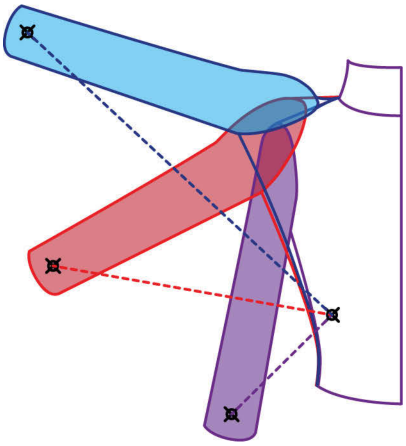
Figure 3: Adding stretch materials to the control points of variable darts can make them more responsive.

In model 1, the act of placing elastic on the control point makes it much more responsive. Using an elastic cord creates other effects compared to a rigid cord.

In model 2, attaching elastic from the garment base to the control point of the variable dart, again changes its behaviour. The elastic adds resistance to the control point and requires it to be pulled with greater force to flatten the pattern.

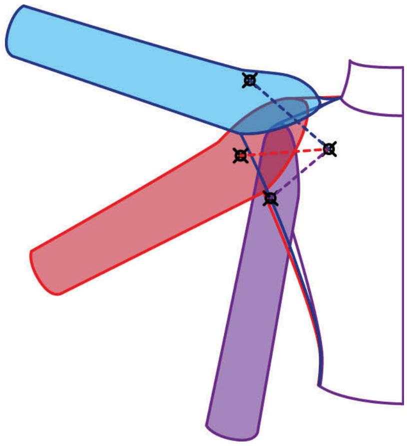
In model 3, attaching elastic on both sides of the control point changes its behaviour. The point requires less force than in model 2 to flatten the dart. When force is removed from the control point, the elastic on both sides of the dart pulls it back to its original shape.

Part 2:



Model 4:

The distance between control points changes greatly when the arms move.



Model 5:

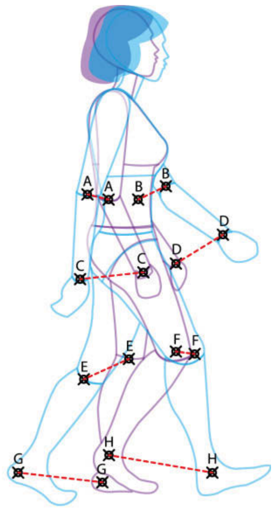
The distance between control points changes very little when the arms move.

Figure 4: The distance between two control points changes when the body moves. This varies depending on where they are placed on the body. For example, control points placed on the arms will change shape more than control points placed on the shoulders.

In model 4, it is observed that there is a great change in distance as the arm is raised above the head. This rapid change in the location of the control point rapidly pulls the structure. For example, if a variable dart is located on the lower left of the back and its control point is on the outer sleeve, raising the arm rapidly changes the shape of the variable dart.

In model 5, it is observed that there is not a great deal of change in distance as the arm is raised above the head. This is a much subtler change in distance. For example, if a variable dart is placed in this position, it changes very little when the arm is raised.

Part 3:



Model 6

Figure 5: Different body parts change position at different rates during body movement.

In Model 6, some body landmarks travel larger distances than others. The elbows (marked “A” and “B”) change very little, as do the knees (marked “E and “F”). Body parts such as ankles (“G” and “H”) and wrists (“C” and “D”) travel further. This information is crucial when designing where to place the control points of variable structures.

Conclusion

The experiment reinforces the importance of control points and how they can modify the interaction of variable structures. Using elastic can change the responsiveness and behaviour of these structures. Knowing the rate at which body landmarks change shape over time is also essential when choosing the location of control points and variable structures.

Experiment 71: Different Configurations of Variable Darts

Rationale, Hypothesis, Design

This experiment explores how different configurations of variable darts can change the geometry of patterns in different ways. Specifically, it examines how to modify the interactions of variable darts with the body. To do this, the research creates configurations by building different base shapes and manipulating the pattern's control points in order to create a variety of functions and effects.

Procedure

The experiment has five parts.

Part 1:

The first iteration investigates how geometry changes the shape of the fabric's surface. By closing and opening a variable dart it is noted how this changes the shape of the dart. It begins with a variable dart with an oblique cone mounted on a flat piece of fabric. The control point of the dart is attached to a fabric cord, making it easier to pull to the control point. The variable dart is pulled with different levels of strength, manipulating the surface of the pattern to different degrees.

Model 1: Leave the variable dart at rest and do not pull on the control point.

Model 2: Pull on the control point to partially close the dart.

Model 3: Pull on the control point to fully close the dart.

Part 2:

The second iteration tests what happens when it puts the control points of variable darts in different places on the body to create different effects. In this example a model is wearing a blouse pattern with sleeves. A variable dart is placed on the head of the sleeve, and the control points are placed on different positions to create different effects. It then observes how the placement of the control points affects the behaviour of the pattern.

Model 4: Place the control point of the variable dart on the side of the arm near the elbow.

Model 5: Place the control point of the variable dart on the chest.

Part 3:

The third iteration explores the possibilities of putting multiple variable darts in different configurations to create different effects. By placing the control point of the variable darts in different locations, it can give parts of the garment different behaviours. These iterations all start with a flat piece of fabric, with variable darts then being attached to them to change their properties.

Model 6: In this model the control points of two darts are attached together. Mount two variable darts on a piece of fabric. Attach the control point of the two variable darts together. Then attach this control point to a rigid fabric cord and attach this to the right of the variable darts.

Model 7: In this model two variable darts are placed facing opposite directions. Mount a variable dart (in pink) that points right. Attach a fabric cord to its control point and attach to cord to the right of the dart. Mount a variable dart (in purple) that points left. Attach a fabric cord to its control point and attach to cord to the left of the dart.

Model 8: In this model the control points of two variable darts are joined, however one of the variable darts is in an open position and the other is in a closed position. Mount a variable dart that is open and make it face the right. Mount a variable dart that is closed and make it point left. Attach the control point of the two darts and attach a cord to them. Attach the cord above the location of the variable darts.

Part 4:

The fourth iteration creates variable darts with different-shaped bases. When variable darts close and open, the shape of the base changes. Having a base of different shapes can change the shape's geometry in diverse ways. The experiment compares one variable dart of a rounded diamond-shaped base with a variable dart with an arrow-shaped base.

Start with a flat piece of fabric. Mount a variable dart with a round-shaped base on the pattern. The cone on this dart is more of a pyramid, in order to neatly attach to the arrow shape. Attach a rigid fabric cord to the control point of the variable dart.

Model 9: Leave the variable dart at rest and do not pull on the control point.

Model 10: Pull on the control point to partially close it.

Model 11: Pull on the control point to fully close the variable dart.

Start with a flat piece of fabric. Mount a variable dart with an arrow-shaped base on the pattern. This round pattern is sometimes called a diamond dart as it has a similar geometric effect as a diamond dart. Attach a rigid fabric cord to the control point of the variable dart.

Model 12: Leave the variable dart at rest and do not pull on the control point.

Model 13: Pull on the control point to partially close it.

Model 14: Pull on the control point to fully close the variable dart.

After creating these models, make observations on the ways closing the variable dart changes the geometry of the patterns.

Part 5:

The fifth iteration uses belt loops, eyelets, elastics and draw strings to modify the properties of variable darts. This explores different ways that each of these components can enhance the behaviour of variable darts. It uses variable darts with cords attached to them to give long control points.

Model 15: Mount a variable dart onto a rectangle of fabric. Attach a belt loop to the fabric at 45° to the control point. Thread the control point of the dart through the belt loop so that the control point is now 90° from the variable dart. This changes the direction of the control point.

Model 16: Mount a variable dart onto a rectangle of fabric. Attach two eyelets next to each other and thread the control point through the garment.

Model 17: Mount a variable dart onto a rectangle of fabric. Attach elastic to the control point of the variable dart. Then attach the elastic to the surface of the fabric.

Model 18: Mount a variable dart onto a rectangle of fabric. Attach an array of six eyelets in rectangular shape. Run the control points through the eyelets like a shoe lace. This creates a shoelace structure on the eyelets and changes the location of the control point.

Results

Part 1:

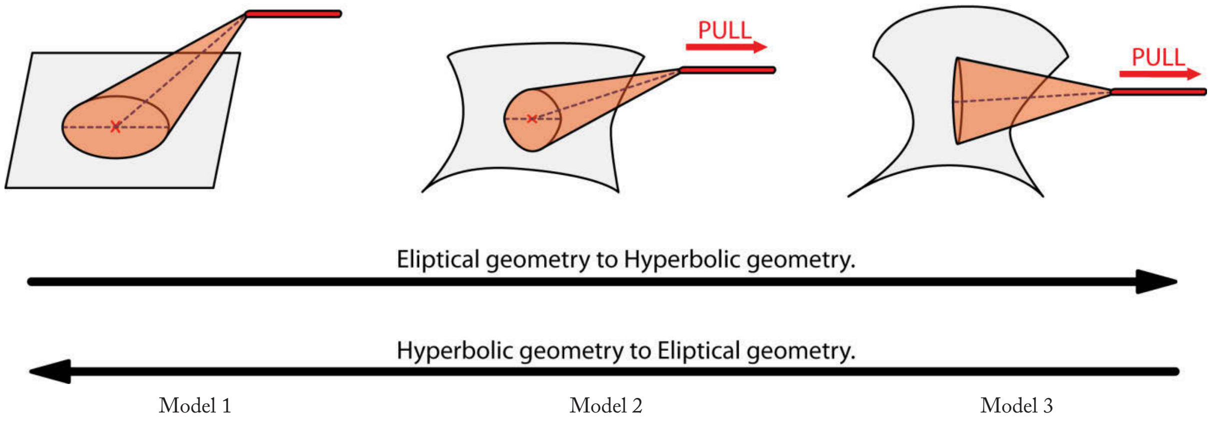


Figure 1: Variable darts can change the geometry of a pattern from elliptical to hyperbolic.

It appears that pulling this variable dart closed causes the surface to become more hyperbolic in shape, while letting the variable dart open makes the surface more elliptical.

Part 2:

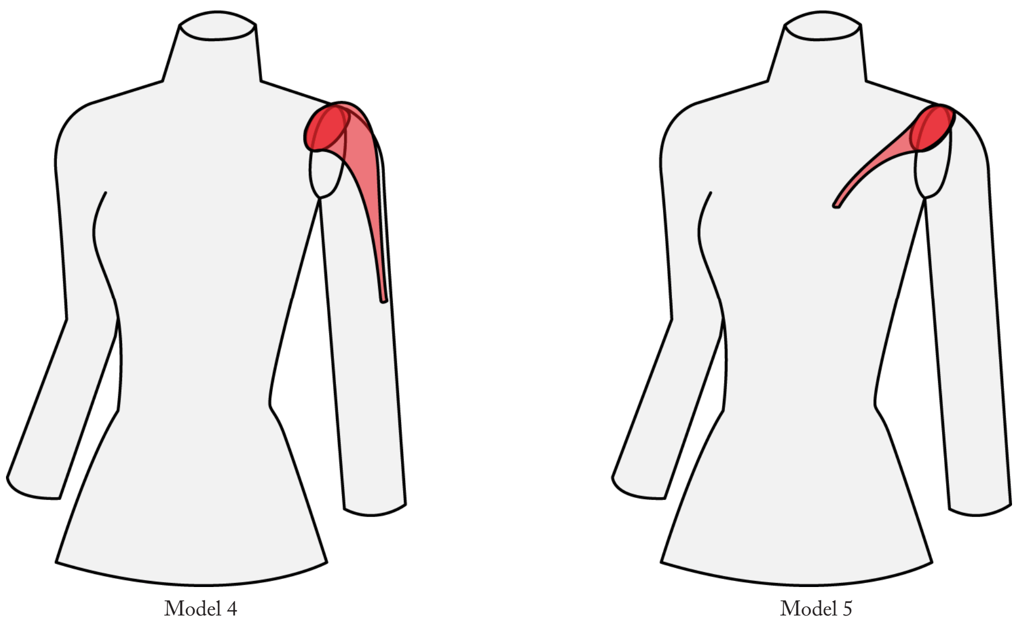


Figure 2: Finding the point on the body that modifies the control point is an important choice when using variable darts.

In model 4, it is noted that the arms move a great distance while the wearer walks. This means that the control point on the arm will be constantly opening and closing the variable dart.

In model 5, the control point is placed on the chest. This part of the body does not move as much when the body moves. The wearer would have to twist their torso or shrug their shoulders in order to change the shape of the variable dart. Placing the control point in this position targets much more specific body movements. The changes in the shape of the variable dart are also much more subtle and less frequent than if placed on the arm.

__Part 3__:

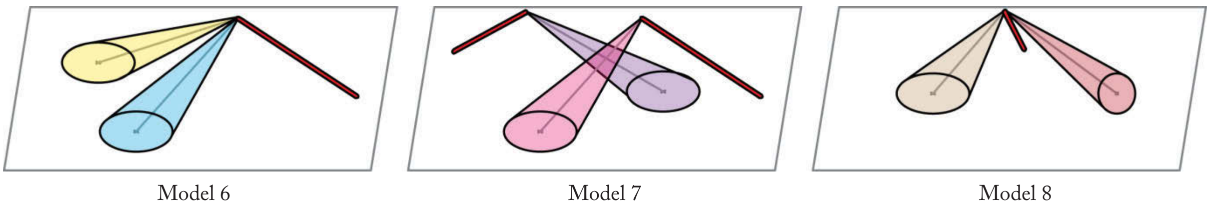


Figure 3: These are examples of two variable darts in different configurations.
Finding the point on the body that modifies the control point is an important choice when using variable darts.

In model 6, the control points of the darts are joined together. This means that one movement can simultaneously close two darts.

In model 7, the two darts face in opposite direction. This means that if the control points are pulled on a single direction, one dart starts to open while the other starts to close. The darts' opposing direction means that movements affect them in an oppositional way.

In model 8, it experiments with attaching together the control points of two darts, even though one is open and the other is closed. If the control point is moved to the left, the grey dart starts to open while the pink dart starts to close. If the control point moves to the right, the grey dart begins to close and the pink dart, to open. Attaching darts in opposing states means that movement affects them in opposing ways.

Part 4:

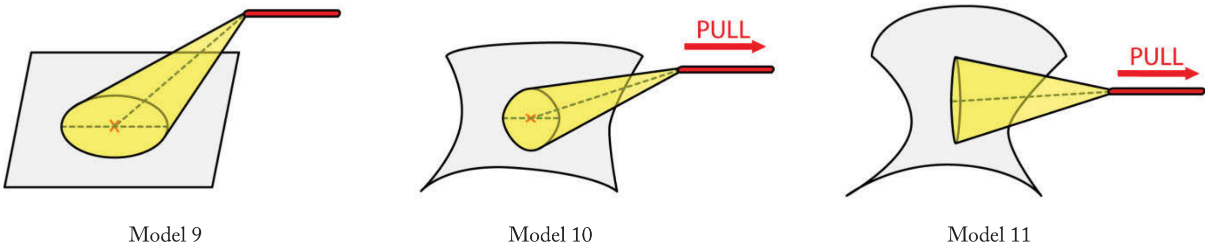


Figure 4: Using variable darts with different-shaped bases allows the geometry of the garment to be controlled in different ways. Using a variable dart with an elliptical-shaped base will make a surface more hyperbolic when closed.

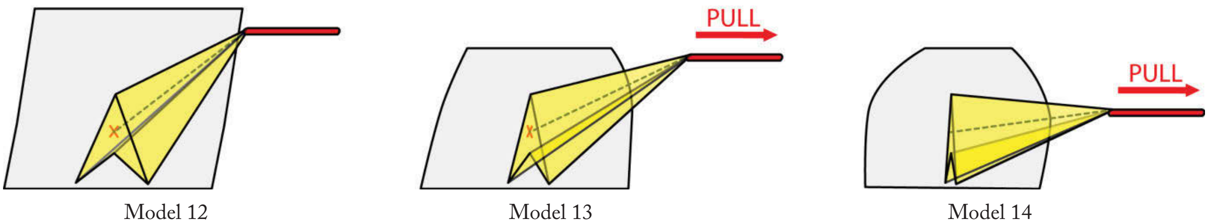
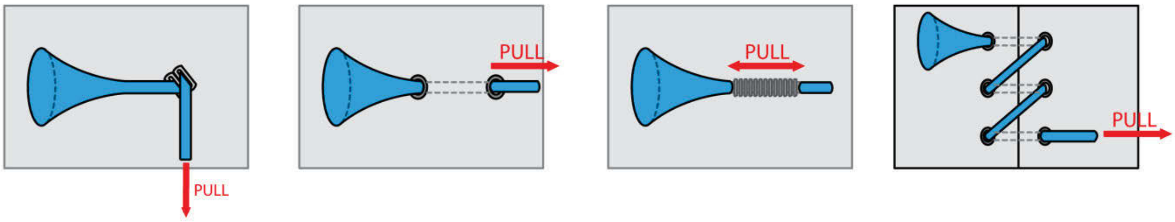


Figure 5: Using a variable dart with an arrow-shaped base ensures the garment becomes more spherical in shape.

In the variable dart with the round base (diamond dart) the fabric becomes more hyperbolic in shape. The variable dart with the arrow-shaped base makes the fabric more elliptical. The round dart creates the effect of a diamond dart, while the arrow-shaped dart creates the effect of a triangular-shaped one. Clearly, designing the base shape of variable darts lets the patternmaker control the garment shape.

Part 5:



Model 15:
Belt loops allow the direction of the end of a variable dart to change direction.

Model 16:
Eyelets allow the control point of a variable dart to be submerged beneath the surface of a garment.

Model 17:
Elastic can be used to control the tension and position of variable darts.

Model 18:
A series of eyelets allows the tension of a laced garment to control the tension of a variable dart.

Figure 6: These are four examples of how using belt loops, eyelets and elastics can create different structural and aesthetic effects on the control point of a variable dart.

It is observed that garment components create diverse ways to change the properties of the variable dart.

In model 15, the belt loop cleverly changes the direction of the control point. This means that the control point can now be pulled in a completely different direction with the capacity to change the shape of the variable dart.

In model 16, placing eyelets on the fabric is an effective way for the control point to weave over and under the fabric. This can be used to create different aesthetic effects.

In model 17, the addition of elastic to the control point made it much more responsive. The pull of the elastic also means that the variable dart will always try to return to a default position, even if the body is changing shape.

In model 18, it is observed that using eyelets is an effective way to change the direction and position of the control point. Using the control points of a shoelace structure has functional applications, such as those used in corsetry and shoe laces. It also can achieve an aesthetic effect.

Conclusion

It is noted that there are many ways of modifying and enhancing the behaviour of variable darts, including modifying the location of control points and placing variable darts in different combinations. Designing the base shape of variable darts allows us to control the pattern's geometry. The use of garment components such as belt loops and eyelets lets the control points of the darts be moved and re-directed in novel ways. In the face of so many ways to modify variable darts, it is up to the designer's imagination to choose what they desire.

18. Variable Structures

Experiment 72: **Singularities**

Experiment 73: **Wormholes**

Experiment 74: **Floating plates**

Experiment 75: **Smart garments**

Experiment 76: **A network**

Experiment 77: **The piston**

Aim

These six experiments explore a variety of variable structures that create diverse functional or aesthetic effects in a garment. The pattern's ability to change shape adds a new dimension of movement, interaction and programmability into fashion patternmaking. The research investigates the ways that variable structures can be combined to create garments with different behaviours.

Method

The experiments explore different variable structures, including singularities, wormholes, floating plates and pistons. These structures can be built into "networks" and can be designed with specific functions in mind. Further, combinations of variable structures empower the patternmaker to generate "smart patterns" that exhibit different behaviours, functions and aesthetic effects.

Analysis

In sum, these experiments explore the important possibilities in diverse variable structures. The goal is to reinforce their distinctly different properties, compared to conventional patterns of singular static shape. Specifically, it notes the ability of variable structures to change shape in time, adding a crucial and exciting new dimension to patternmaking.

Experiment 72: Singularities

Rationale

This experiment explores a patternmaking structure called a "singularity", which is a tube that connects to a flat piece of material. This is a way of funnelling a large surface area of fabric into a small point on a two-dimensional surface.

Hypothesis

The research anticipates the use of singularities to create a variety of structures and effects.

Experimental Design

It explores the properties of a singularity. The shape of variable structures is often inspired by the geometry of space. The singularity, inspired by the structure of a black hole, is in fact a funnel-shaped structure inserted into the garment's flat surface.

Procedure

The experiment has one part.

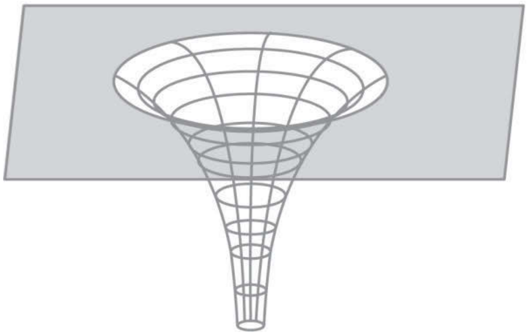
Part 1:

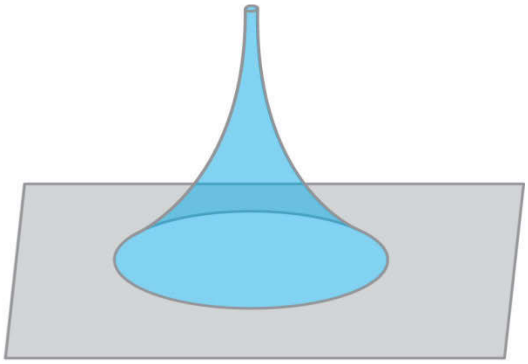
Model 1: Start with a flat piece of fabric and cut a large circle in the centre. Mount a funnel-shaped singularity in the middle of the pattern and sew it into the pattern. Make observations about the singularity (see figures 1 and 2, below).

Model 2: Create and identical copy of model 1, then turn the pattern upside down so that the singularity is on the outside of the garment (see figures 1 and 2). Make observations about this structure.

Results

Part 1:





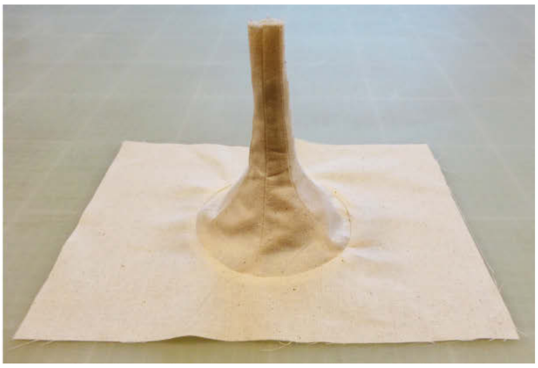
Model 1:

The structure of a singularity.

Model 2:

A singularity on the surface of the garment.

Figure 1: A singularity is a structure that allows a small part of the garment to have a highly concentrated surface area. Moving the end of the singularity allows materials to be added or subtracted from the surface of the garment.



Model 1:

The structure of a singularity.

Model 2:

A singularity on the surface of the garment.

Figure 2: A fabric structure of the models in **Figure 1.**

Observations

The long tube of the singularity structure allows a large surface area to be compressed into a very small point, such that if this structure is placed on the body, it may increase or decrease the amount of surface area in the singularity. By moving the end of the singularity, the patternmaker can change the surface shape in a way similar to a cone mounted on a variable dart. Singularities differ from cones on variable darts in that they are long funnel-like shapes and their ends are "tunnels". The latter forms a control point that can change the shape of the singularity's opening. When placed under the surface, singularities can conceal additional material, and when placed on the top of the garment they become a design feature.

Conclusion

The singularity is a structure that allows the geometry of a small area to be manipulated by moving its control point. The research anticipates that singularities can be combined to create more complex variable structures in future experiments.

Experiment 73: Wormholes

Rationale

This experiment explores a patternmaking structure known as a wormhole. This is a structure created by joining two singularities together. It allows the patternmaker to manipulate a garment by changing the geometric shape of the garment surface. It investigates ways wormholes can be used to create variable structures.

Hypothesis

By using wormholes, the research anticipates the creation of a variety of structures and effects.

Experimental Design

The shape of variable structures is often inspired by the geometry of space, and this particular one is inspired by the wormhole. The first iteration examines the wormhole's properties, and the second explores ways they can create different functions and effects.

Procedure

The experiment consists of two parts.

<u>Part 1</u>:

Set 1:

The first iteration examines the wormhole's properties. It is created by joining two singularities by means of a long tunnel.

Model 1: Start with a flat piece of fabric and create a wormhole that is mounted beneath the surface of the garment.

Model 2: Start with a flat piece of fabric and create a wormhole that is mounted on top of the surface of the garment.

Observe the structures of the wormhole and how this affects the garment's structure and aesthetics.

Set 2:

Create a wormhole on a flat piece of fabric. Test how moving the position of the tunnel of the wormhole changes the shape of the garment.

Model 3: Pull the tunnel of the wormhole to the left side of the garment.

Model 4: Leave the wormhole at rest.

Model 5: Pull the tunnel of the wormhole to the right side of the garment.

Part 2:

Set 3:

This iteration explores nesting a wormhole inside another wormhole.

Model 6: Create a wormhole (in blue) on a piece of flat fabric by joining two singularities together. Create another wormhole (in red) on the outside of the first wormhole and run the tunnel joining the two wormholes through the first wormhole. This nests one wormhole inside another. Observe the properties of this structure.

Set 4:

This iteration explores how variable structures can be mounted inside a wormhole.

Model 7: Create a wormhole on a flat piece of fabric with the tunnel of the wormhole submerged beneath the surface of the garment. Create another singularity next to the wormhole. Attach the control point of the singularity inside the tunnel of the wormhole.

Set 5:

Start with a flat piece of fabric. Create two singularities next to each other. Join the ends of the singularity with elastic. This should create a wormhole that has a tunnel made out of elastic.

Model 8: Leave the wormhole at rest.

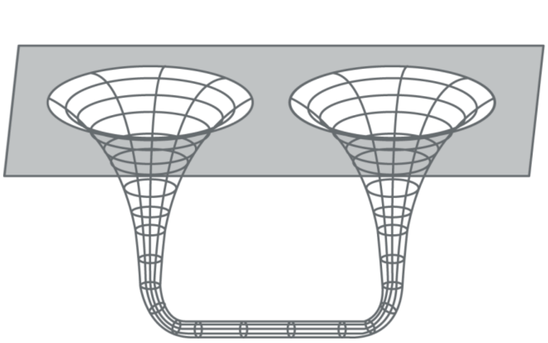
Model 9: Pull apart the sides of the fabric to stretch the wormhole, and observe how this affects the pattern.

Model 10: Push together the sides of the fabric so that they contract, and observe how this affects the pattern.

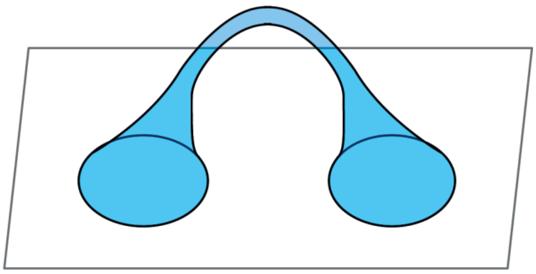
<u>**Results**</u>

<u>**Part 1:**</u>

Set 1:



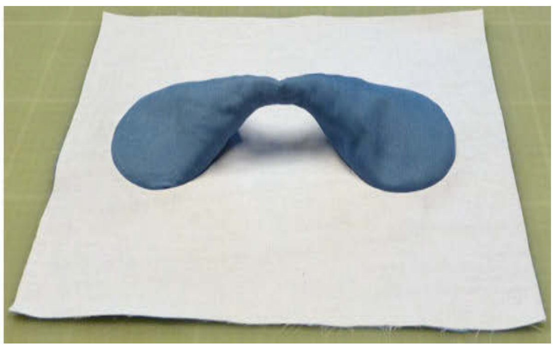
Model 1:
The structure of a wormhole.



Model 2:
A wormhole on the surface of a garment.

Figure 1: A wormhole is created by attaching the ends of two singularities together. This allows the geometry of two different locations to be manipulated. The two ends of the wormhole are also connected to each other and the tunnel joining them allows them to interact.

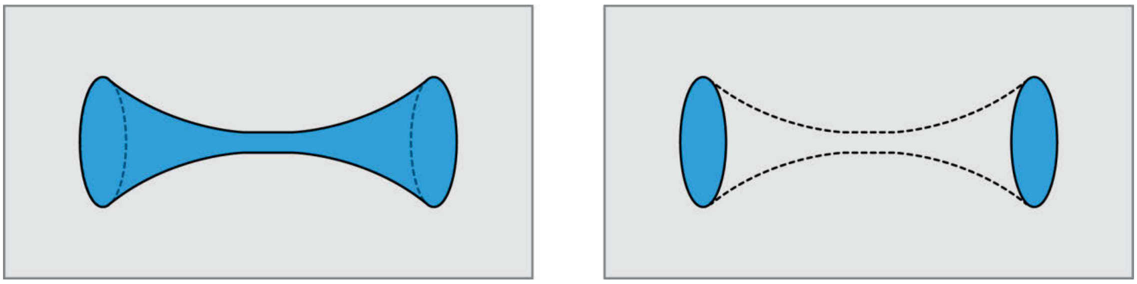
Model 1:
The structure of a wormhole.



Model 2:
A wormhole on the surface of a garment.

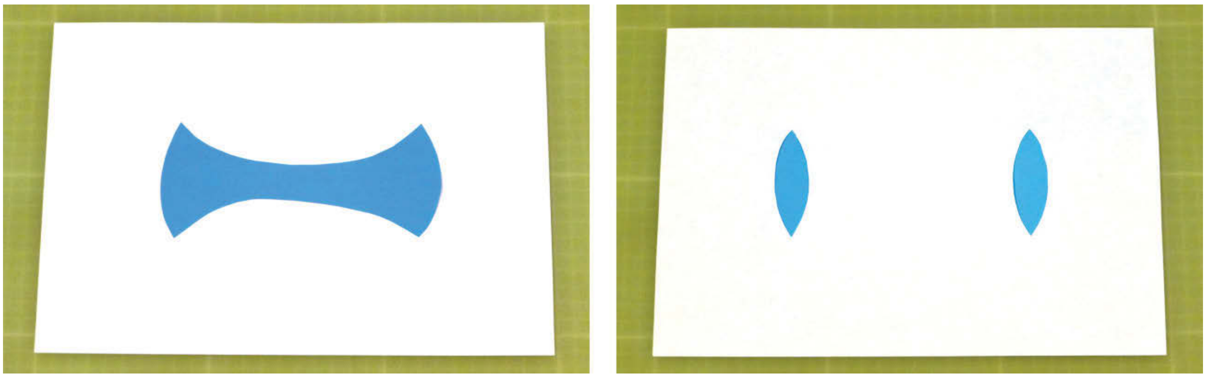
Figure 2: Physical models of **Figure 1.**

From models 1 and 2, it is observed that a wormhole is an extremely useful structure, able to store additional material and release it on different sides of the tunnel. By placing the wormhole on the outside of the garment, the structure can create an aesthetic affect, while placing it on the inside creates a much more subtle effect (figure 2).



Outside Inside

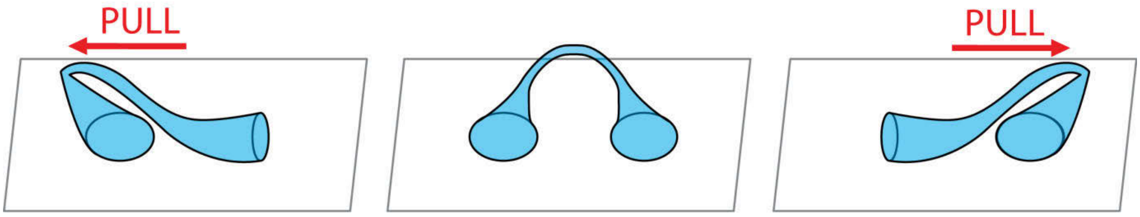
Figure 3: A wormhole can run above or below the surface of a garment. These structures create different aesthetic effects.



Outside Inside

Figure 4: A physical model of **Figure 3.**

Set 2:



Model 3:	Model 4:	Model 5:
The wormhole's tunnel is moved to the left. The right side of the garment changes shape.	The wormhole's tunnel is centred.	The wormhole's tunnel is moved to the right. The left side of the garment changes shape.

Figure 5: Moving the position of the tunnel of the wormhole causes the geometry of the garment to change shape.

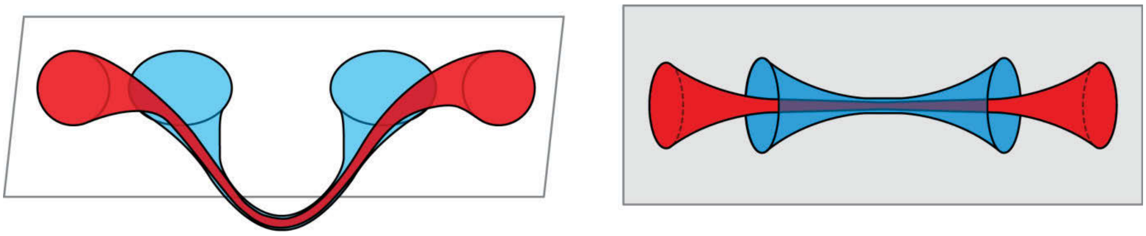
Model 3:	Model 4:	Model 5:
The wormhole's tunnel is moved to the left. The right side of the garment changes shape.	The wormhole's tunnel is centred.	The wormhole's tunnel is moved to the right. The left side of the garment changes shape.

Figure 6: Fabric models of **Figure 5.**

In model 3, the wormhole is pulled to the left, causing the right side of the wormhole to close, but the left side of the wormhole to open. In Model 4, where the wormhole's tunnel is left to rest, the two sides of the wormhole remain the same size. In model 5, the wormhole is pulled to the right, causing the wormhole's left side to close and the right to open. It is observed that manipulating the position of the tunnel controls both ends of the wormhole. This is akin to two sets of variable darts that are connected to each other.

<u>Part 2</u>:

Set 3:



Side view

Top view

Model 6

Figure 7: Wormholes can be nested inside other wormholes. These offer different structural, functional and aesthetic effects.

It is noted that nesting a wormhole within another, allows the wormhole to be concealed beneath the garment's surface. Alternatively, when placed on its top, they offer an aesthetic feature.

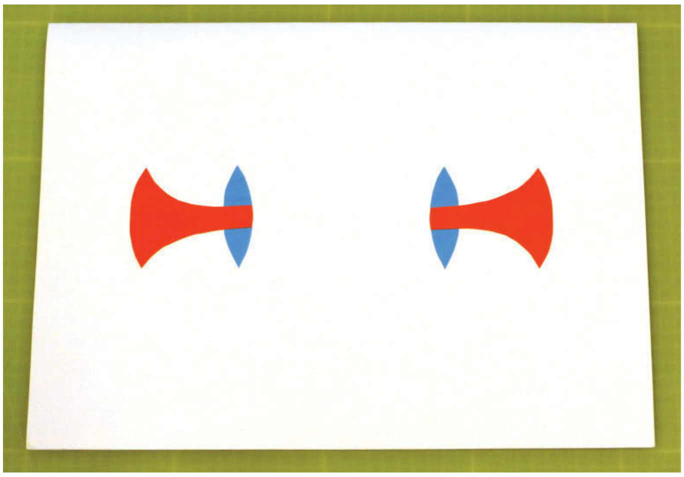
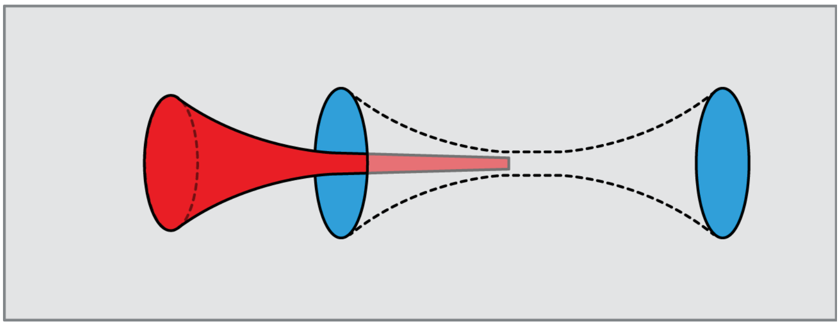


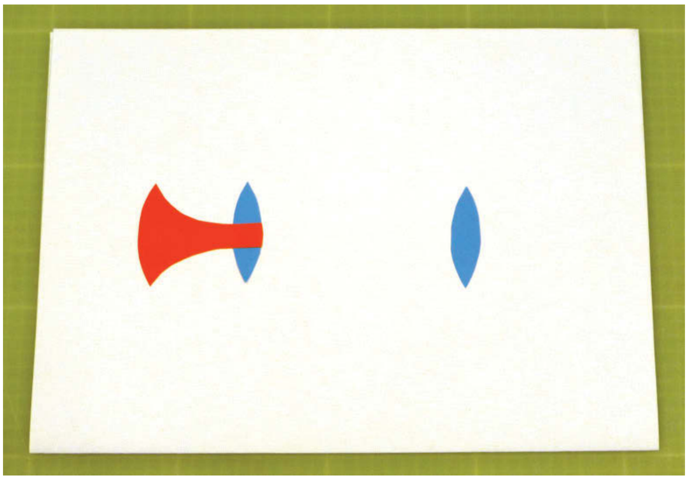
Figure 8: A physical model of **Figure 7.**

Set 4:



Model 7

Figure 9: The control point of a variable dart is nested inside a wormhole.

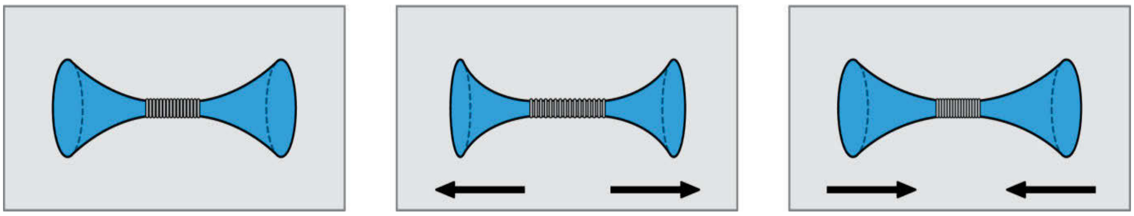


Model 7

Figure 10: A physical model of **Figure 9.**

In model 7, the control point of the singularity is attached inside the wormhole. This means that if the tunnel of the wormhole is moved, the area controlled by the singularity will change shape. This has an effective aesthetic effect, as the singularity will be pulled inside the wormhole, creating the shape of the fabric's surface without making creases.

Set 5:



Model 8: A wormhole with elastic in a resting position.

Model 9: A wormhole with elastic stretched apart.

Model 10: A wormhole with elastic compressed together.

Figure 11: A wormhole joined by elastic can control the tension of the garment's surface.

In model 8, the elasticated wormhole maintains the tension of the wormhole's two ends. In model 9, the stretching of the fabric causes the two ends to close, changing the surface shape and tightening the garment shape. In model 10, compressing the fabric causes the wormhole's ends to open up, loosening the fit of the garment. Thus it is observed that elasticated wormholes adjust to the changing shape of the body.

Conclusion

It is noted that there are multiple ways of using wormholes to dynamically change the shape of the pattern. Its shape can be modified by placing wormholes above or below the garment's surface. Further, other variable structures can be nested inside the wormholes. Notably, the addition of elastics to wormholes can deftly change their behaviour.

Experiment 74: Floating Plates

Rationale

This experiment investigates the properties of a patternmaking structure called a "floating plate". It is designed to float on the garment's surface and constantly change shape to accommodate movement. Its edges are variable structures and can change shape. They are mounted in wormhole structures, allowing the edges to submerge beneath the garment's surface. This is a way of subtracting or adding materials without creating wrinkles. The tension of the floating plate is controlled by elastic attached to it. Floating plates may have different configurations and connect to multiple wormholes.

Hypothesis

The research anticipates building a floating plate that can accommodate a wide variety of movement.

Experimental Design

The shape of variable structures is often inspired by phenomena in nature, and the floating plate is inspired by the floating behaviour of tectonic plates on the Earth's crust. With tectonic plates, the edges submerge beneath the surface of others. This inspired the research to create part of a garment that dynamically changes shape, while any excess material is pulled beneath the garment's surface.

The first iteration builds a floating plate that submerges into two wormholes. It then moves the plate's position to show movement in time. The second iteration creates a floating plate that submerges under three wormholes. It then observes the movement of the structure.

Procedure

The experiment has two parts.

<u>**Part 1**</u>**:**

Start with a flat rectangular piece of fabric. Cut a round hole in the pattern. This will be the part of the garment that is constantly changing shape. Cut two circles that are larger than the hole in the pattern. Join these two circles together to create the "floating plate" (see figure 1, below). Cut a hole in the bottom of the floating plate and attach it to the fabric (see figure 1). This plate will move across the surface of the body, covering the part of the garment that is constantly changing shape. Attach two singularities (in orange) to the left and right of the floating plate. Put elastic on the control points of the singularities so that they pull the floating plate to the surface of the pattern with tension. Nest the ends of the singularities inside two different wormholes. This creates a floating plate structure with two different wormholes.

Model 1: Leave the floating plate at rest in its default position.

Model 2: Bend the fabric so that the floating plate moves to the right.

Use a physical model of the floating plate and move the location of the plate to different positions.

Model 3: Move the floating plate to the left.

Model 4: Move the floating plate to the centre.

Model 5: Move the floating plate to the right.

Make observations on how the patterns change over time.

<u>Part 2</u>:

Start with a flat rectangular piece of fabric. Cut a round hole in the pattern that will constitute the part of the garment that is constantly changing shape. Cut two circles that are larger than the hole in the centre of the pattern. Join these two circles together to create the floating plate (see figure 1). Cut a hole in the bottom of the floating plate and attach it to the fabric (see figure 1). This plate will move across the surface of the body, covering the part of the garment that is constantly changing shape. Attach three singularities (in orange) to the floating plate. Put elastic on the control points of the singularities so that they pull the floating plate to the surface of the pattern with tension. Nest the ends of the singularities inside three different wormholes. This creates a floating plate structure with three different wormholes.

Model 6: Leave the floating plate at rest in its default position.

Model 7: Bend the fabric so that the floating plate moves to the right.

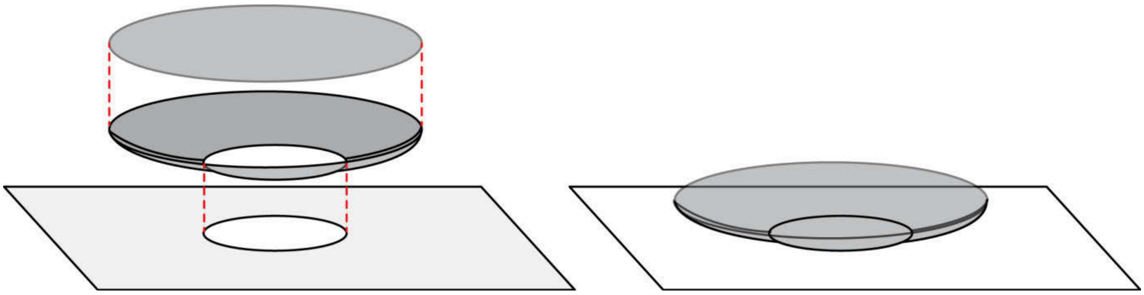
Use a physical model of the floating plate and move the location of the plate to different positions.

Model 8: Move the floating plate to the left.

Model 9: Move the floating plate to the right.

Model 10: Move the floating plate into the centre.

Make observations on how the patterns change over time.

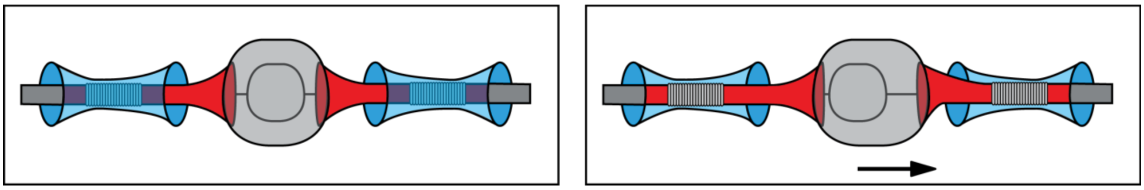


Assembling the floating plate. The floating plate.

Figure 1: The floating plate is a fabric structure that floats on the garment's surface and constantly changes shape to accommodate movement.

Results

Part 1:



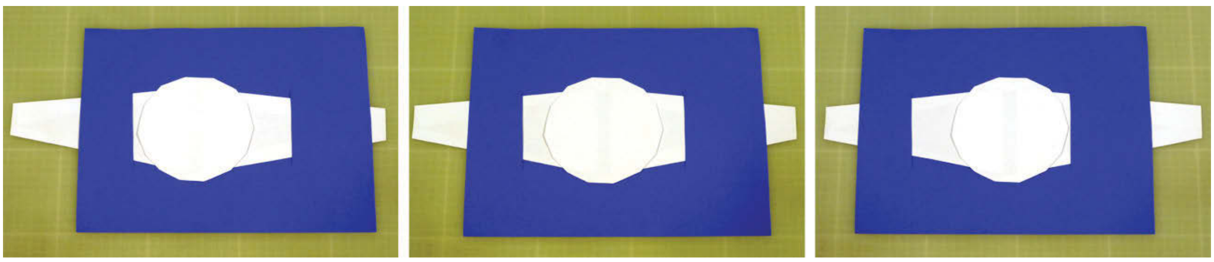
Model 1:

A floating plate mounted inside two wormholes.

Model 2:

A floating plate moving position.

Figure 2: A floating plate is a structure where the edges of the garment can submerge beneath the garment surface into wormholes. The tension of the floating plate is controlled by elastic mounted in the wormholes.



Model 3:

A floating plate moving to the left.

Model 4:

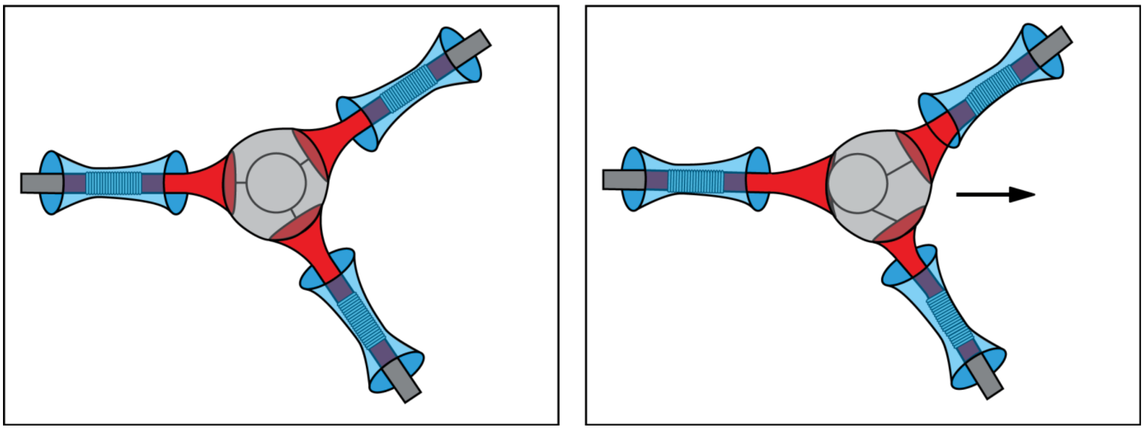
A floating plate centred.

Model 5:

A floating plate moving to the right.

Figure 3: A paper model of a floating plate mounted in two wormholes moving in different position.

Part 2:



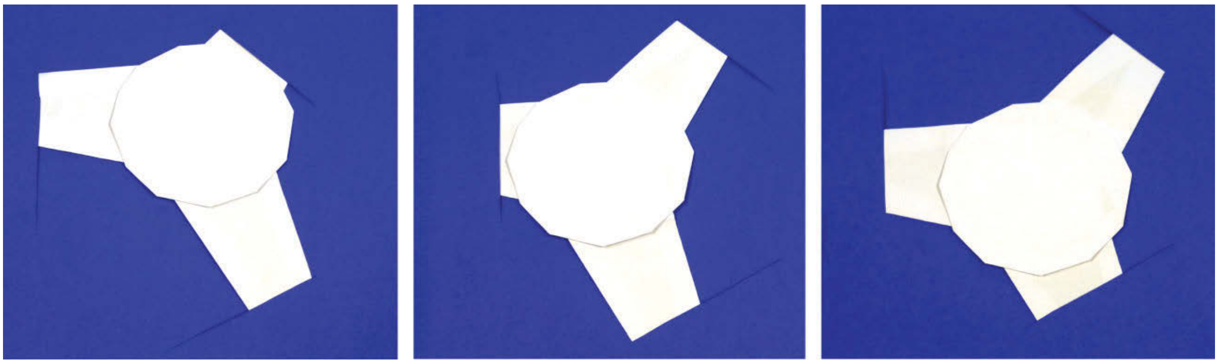
Model 6:

A floating plate mounted inside three wormholes.

Model 7:

A floating plate moving position to the right.

Figure 4: A floating plate with multiple wormholes allows the plate to move widely.



Model 8:

The floating plate moving up to the left.

Model 9:

The floating plate moving to the right.

Model 10:

The floating plate moving down in the centre.

Figure 5: A paper model of a floating plate mounted in three wormholes moving in a wide range of positions.

Observations

In a floating plate structure, the plate is pulled at different angles by elastic. As the tension of the fabric changes, so does the shape of the plate. One advantage of mounting the singularities inside wormholes is that any excess material is pulled beneath the fabric's surface. If the wormholes are left on the outside of the fabric, it creates a distinctive aesthetic. Placing the wormholes on the outside also lets the tension of the elastic pull the entire structure towards the body.

Conclusion

Floating plates are built from a combination of singularities, wormholes and the plate structure itself. The plate creates a variable pattern that changes shape over time and adapts to the shape of the wearer. It can be placed on parts of the body that change shape constantly, such as on the shoulders. In sum, this structure is a bright example of the kinds of exotic patterns that can be created by combining variable structures.

Experiment 75: Smart Garments

Rationale

This experiment seeks a way to record a garment pattern that changes in time. Conventional fashion patterns record the body at a single moment in time. The alternative approach captures the entire range of movement as a series of dynamically-changing patterns in time, and it seeks a technique by which patternmakers can design such patterns. This will help them create better-fitting garments and new fashion aesthetics. Fashion futurists speculate that it is possible to create future garments using "smart materials" that can be programmed to change shape to fit (Lee 2005, pp. 109 - 126). This new generation of smart materials is often seen as a panacea for fitting problems. Even if such materials become commercially viable, patternmakers still need a form of notation to determine which parts of the garment need to change shape.

Hypothesis

The research anticipates that there should be a way to describe dynamic patterns in greater depth.

Experimental Design

The experiment attempts to establish terminology that can be used to describe patterns that change in time. The introduction of variable structures and mapping patterns that change shape in time requires new methods of recording. The research has borrowed terminology from fields with existing terms to describe similar phenomena, notably electronics and film.

Procedure

The research observes the shape of a pattern as it bends in time. The first iteration describes the pattern with terms from electronics. The second uses film terms to describe the same phenomenon.

Part 1:

Create three models of a pattern that bends over time. Record the three-dimensional shape and the flat pattern. Label each of these patterns as a different "state" - a term borrowed from electronics terminology to describe devices that continually change configuration in time.

Model 1: Create a cylindrical tube of a pattern.

Model 2: Bend the cylindrical tube and create a bend joint at a 135° angle.

Model 3: Bend the pattern even further, so that the pattern bends at a 45° angle.

Label each of these patterns as a different "state". Each can be referred to as a flat pattern in a different state.

Part 2:

The second iteration uses terms from film to describe a series of patterns. Following the previous iteration, create a series of patterns that describe a cylindrical tube as it bends in time. This time, instead of three patterns create a sequence of five. Record each pattern as a three-dimensional pattern and as a flat pattern.

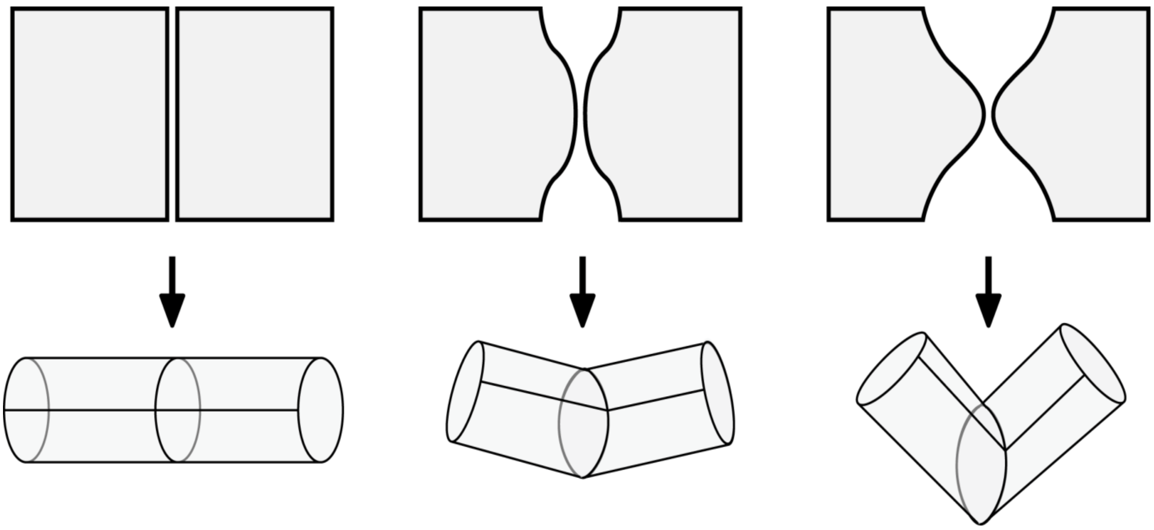
Model 4: Apply terms from film to describe the patterns as they change over time. Take each pattern and label them as a "key frame" (or "frame" for short). Locate each of the patterns on a "timeline". They should appear as if they are a sequence of images on celluloid.

Model 5: Take any image for the sequence and cut the "frame" out of the sequence to analyse the pattern in that moment in time. It is possible to assess any frame in the sequence of images as a pattern of a moment in time.

Film as an analogy for describing variable patterns, offers a framework for patternmakers to describe complex transformations in time.

Results

Part 1:

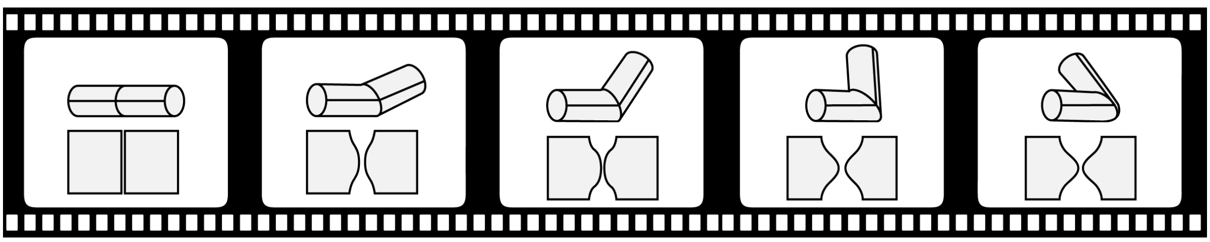


Model 1: State 1. Model 2: State 2. Model 3: State 3.

Figure 1: A variable pattern transforms between different states over time.

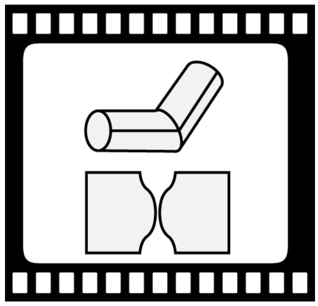
It is observed that the idea of using "states" to describe the patterns works well. However, in electronics, "states" are often used to describe whether a switch is turned on or off. This works when there are only a few states. More than three states can become cumbersome to describe.

Part 2:



Model 4

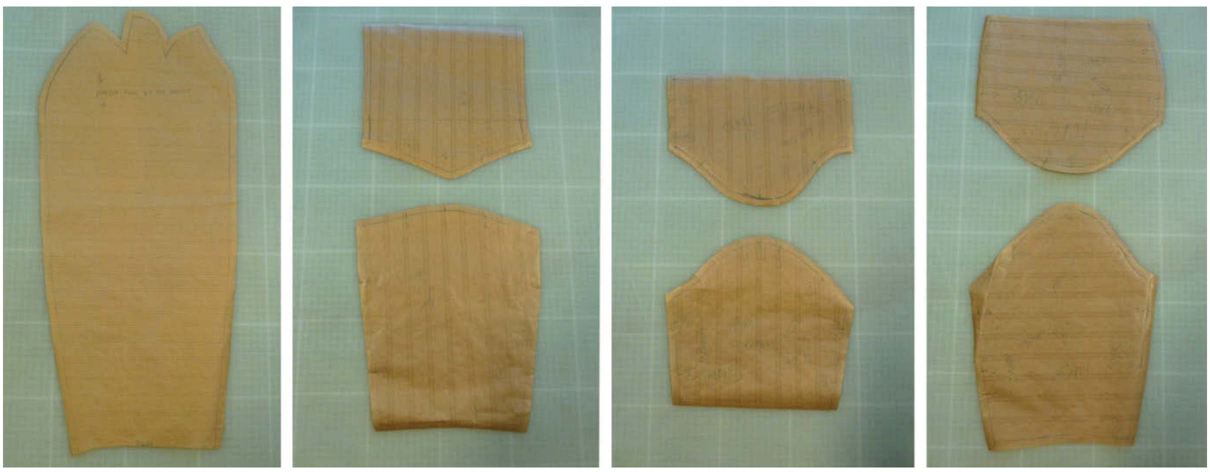
Figure 2: A pattern is recorded for the body shape for each instance in time, making a sequence similar to a strip of celluloid film.



Model 5

Figure 3: The body at each instance in time, is recorded as a single frame in a sequence of patterns.

Draped pattern — Draped pattern — Draped pattern — Draped pattern



Flat pattern. Straight sleeve. — Flat pattern. Sleeve with 45° bend. — Flat pattern. Sleeve with 90° bend. — Flat pattern. Sleeve with 135° bend.

Figure 4: Body movement can be mapped in a sequence of flat patterns.

It is observed that any body movement can be deconstructed into a series of flat patterns (see figure 4). Using film to describe variable patterns is an effective analogy, and a technique many people are familiar with. It is also a physically tangible way of describing an abstract concept like time. In computer graphics terminology, the process of taking multiple 3D scans in time is referred to as a 4D scan. This methodology allows fashion designers to use the concept in patternmaking. In short, it creates a visible timeline to describe pattern changes and developments.

Conclusion

The experiment shows how the changing movement of a pattern can be recorded as a series of flat patterns in time. The pattern shape can be analysed as an individual "state" or "frame" on a timeline. This lets patternmakers make sense of garments that change shape in time, allowing them to more easily design patterns that incorporate variable structures.

Experiment 76: A Network

Rationale

This experiment explores the way variable structures can combine to create complex interactions. Variable structures can create networks of interacting structures that change shape in time depending on body movement.

Hypothesis

The research anticipates that by combining different variable structures, their configurations can be built to perform a specific function or display a specific behaviour.

Experimental Design

The experiment sets up patterns with several variable darts, designed to interact in a way that creates a specific function or behaviour. The first iteration joins several variable darts together, noting how the pattern transforms when the variable dart is opened and closed. The second shows how to build a pattern using different variable structures. The pattern uses diverse techniques to modify the relationships between different structures, including the control points of variable darts that run through wormholes. Control points are also connected using elastics, that will alter the interaction of the variable structures.

Procedure

The first iteration joins several variable darts together.

Part 1:

To create the variable darts, cut an elliptical hole out of the pattern and attach an oblique cone on the hole. This creates a dart that is open when the oblique cone is upright and closed when the oblique cone is flattened.

Create a variable dart (shaded in light blue). Create two variable darts (shaded in purple and orange) to the left of the first dart and attach their control points to the side of the first variable dart.

Create another variable dart (shaded pink) to the right of the initial variable dart. Join the tips of the control points using a fabric cord.

Model 1: Leave the variable dart in the open position.

Model 2: Move the variable dart into the closed position.

Observe the interactions of the pattern in open compared to closed positions.

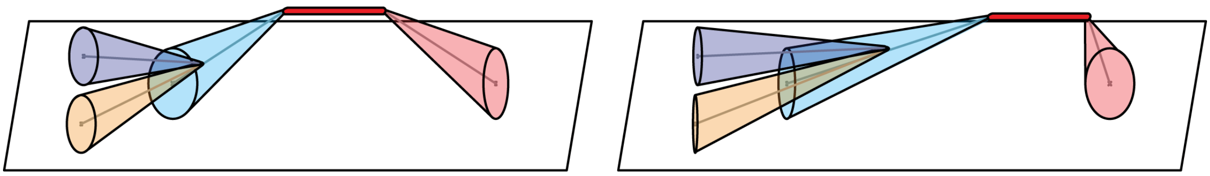
Part 2:

The second iteration combines several variable structures to create a complex variable structure.

Model 3: Create two variable darts (shaded in green) and attach the control points together. Join the control point to a rigid piece of material (shaded in grey) that has a piece of elastic sewn into the centre. Create a wormhole (shaded in blue) and thread the rigid piece of material through it. Create another variable dart (shaded pink) and join the control point of the (grey) rigid piece of material onto the side of the variable dart. Join an additional two variable darts (shaded in yellow and purple) with elasticated control point onto the (pink) variable dart. Create another variable dart (yellow). Join the control point of the (pink) variable dart to the end of the (yellow) variable dart with elastic.

Results

Part 1:



Model 1:
Open.

Model 2:
Closed.

Figure 1: This network of darts means that if the dart on the right opens, then three darts on the left will close.

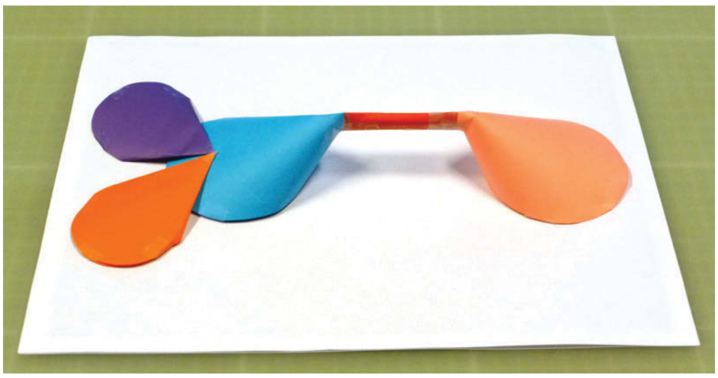
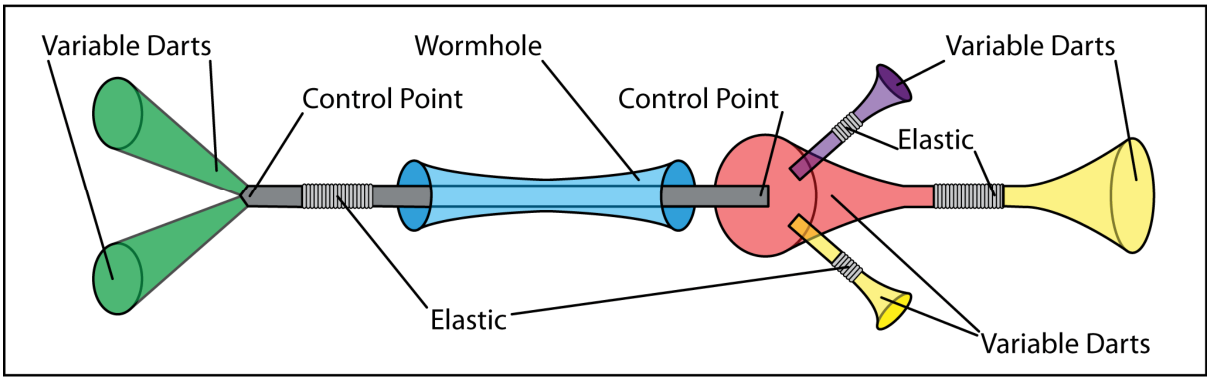


Figure 2: A physical version of model 1.

It is noted that closing the (blue) variable dart closes the purple and orange variable darts, while opening up the pink variable dart.

Part 2:



Model 3

Figure 3: Networks of variable structures can be very complex. This structure has multiple variable darts nested in wormholes.

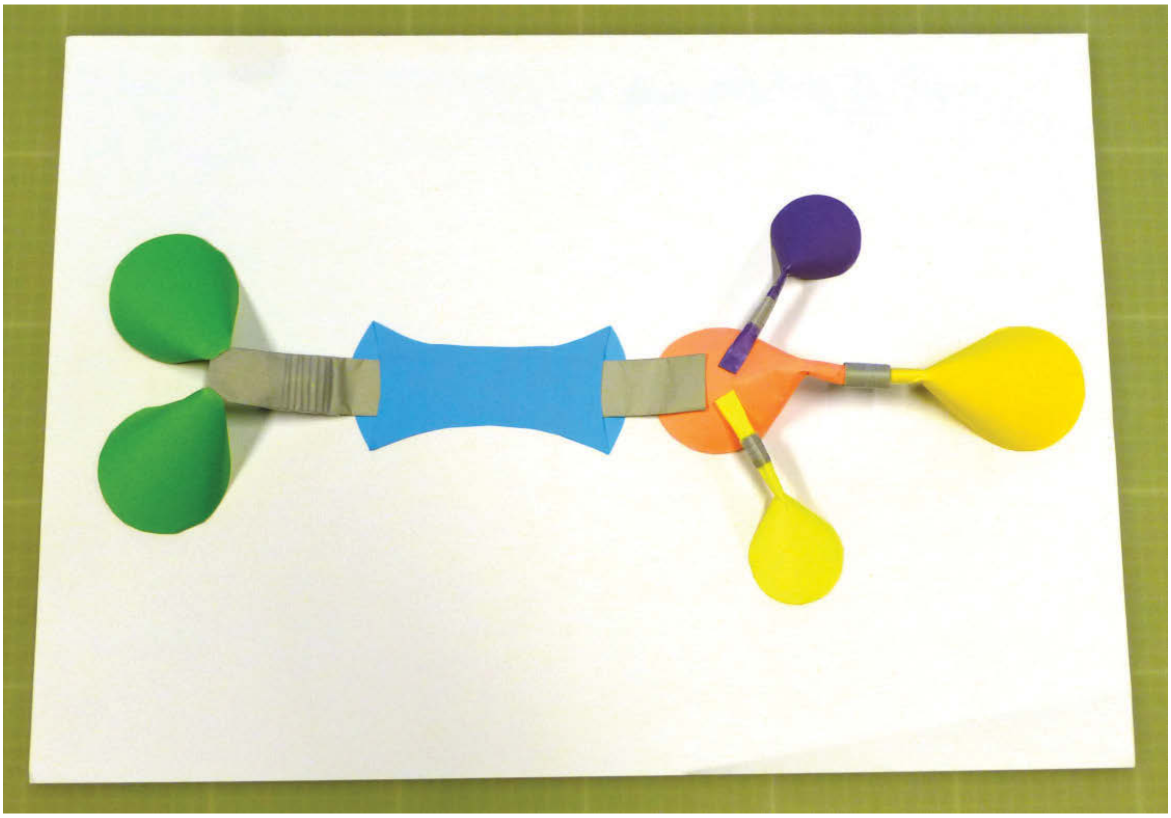


Figure 4: A physical version of model 3.

It is observed that closing the red variable dart opens up the yellow variable dart, opens up the purple and yellow variable darts and closes the green variable darts. The wormhole creates the effect of a long piece of fabric passing beneath the fabric's surface. In sum, pushing and pulling on any part of the variable dart affects every other variable structure in the pattern.

Conclusion

The experiment shows that it is possible to combine multiple variable structures to create a garment that will behave in different ways when affected by body movement. The combination of these structures allows more complex interaction with body movement.

Experiment 77: The Piston

Rationale

This experiment explores the properties of a patternmaking structure called the piston, a structure that is rigid in the centre with elastic attached to opposite sides. This configuration puts equal tension on both sides of the structure, while the centre of the piston stays in the same position while at rest. When the centre is pulled, it deforms the structure's shape, and when force is taken away, the elastic pulls the piston back to a default position. Further, by placing the control point of a variable dart on a piston, it ensures that the control point will always return to its original position when force is removed.

Hypothesis

The research anticipates that pistons will offer more responsive interactions in variable structures, giving patternmakers greater opportunities to control variable darts.

Experimental Design

The research shows how a piston can be used in conjunction with variable darts. The first iteration shows how it works, and the second shows how placing the control point of a variable dart on it, changes the properties of the variable dart.

Procedure

The experiment has two parts.

<u>Part 1</u>:

Diagram 1: Create a piston by taking a rigid piece of material (shaded in red). This may be a piece of fabric that has been stiffened with glue or with a facing. Alternatively, a flexible piece of plastic such as soft boning can be used. Attach elastic of the same lengths on both sides. These add equal tension to both. Attach the elastic to rigid pieces of fabric on both ends of the elastic. Attach these pieces to a flat piece of fabric. Observe the properties of the piston.

<u>Part 2</u>:

Diagram 2: Start with a piston and attach it to the control point of a variable dart. Make observations on how the properties of the piston will affect the variable dart.

Results

Part 1:

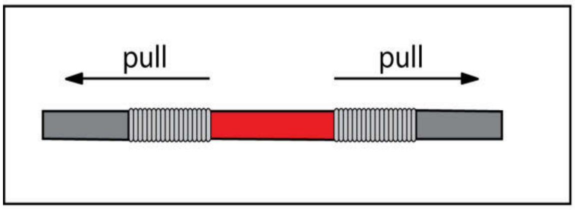
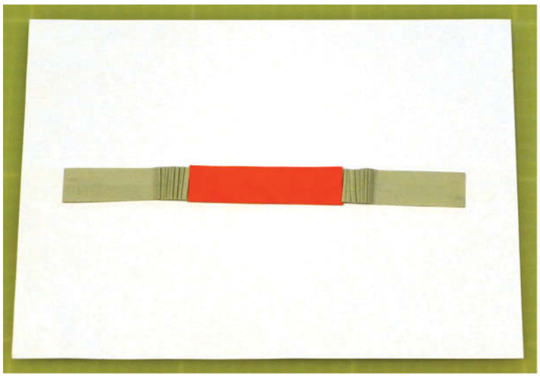
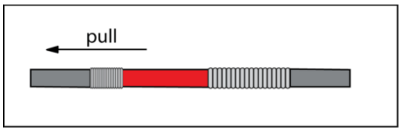


Diagram 1:
Elastic on both sides of a piston gives it tension but does not cause the position of the piston to move.

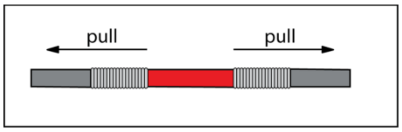


A physical model of diagram 1

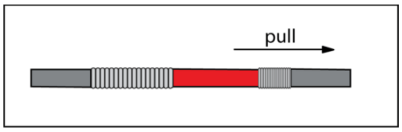
Figure 1: A piston has elastic on both sides. This gives the structure equal tension and means that if it is moved out of a default position the elastic will pull it back to that default position.



A piston pulled to the left.



A piston at rest.



A piston pulled to the right.

Figure 2: A piston pulled in different directions.

Part 2:

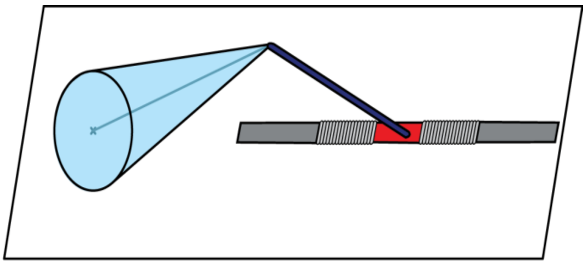
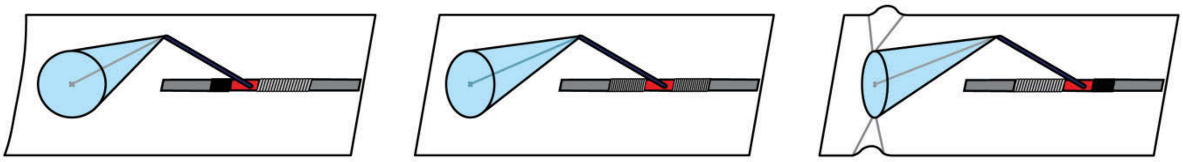


Diagram 2:
Placing the control point of a dart on the piston makes sure the control point will return to a default position when moved.

A physical model of diagram 2

Figure 3: The control point of a variable dart attached to a piston.



A piston pulled to the right. A piston at rest. A piston pulled to the right.

Figure 4: The control point of a variable dart attached to a piston as it changes position.

Observations

It is observed that when the centre part of the piston is pulled then released, the elastic in the piston will return it to its original position. It is also noted that the tension at which the piston is attached to the fabric will determine the responsiveness of the piston. In diagram 2, the properties of the piston makes the shape of the variable dart far more responsive than if it is just attached to a part of the body.

Conclusion

The experiment shows how a piston can be used with a variable dart to create more responsive control points. This can be used to control the behaviour of variable structures for different functional and aesthetic effects.

CONCLUSION

The research in this thesis envisions a future where the application of concepts from science and mathematics will rapidly advance the traditional craft of fashion patternmaking. Fashion technologists and patternmakers have identified that traditional techniques are fundamentally limited in both their accuracy and lack of scientific methodology. This systemic problem pervades the fashion industry, from traditional patternmaking techniques to mass manufacture of clothes, and even limits the development of computer algorithms used to draft patterns from 3D body scans. Improvement in the rigour of patternmaking techniques will benefit many areas of the fashion industry.

Our research applies concepts from Non-Euclidean geometry to address systemic problems in drafting flat patterns from linear measurements. Non-Euclidean geometry is the geometric scheme that governs curved surfaces. Its rules are completely different from the geometry of flat or Euclidean surfaces. From a mathematical perspective traditional patternmaking techniques will always be limited since they use Euclidean mathematics and thinking, to try to measure and record curved Non-Euclidean surfaces.

Our approach to traditional techniques from a geometric perspective has made it possible to question existing practises and invent new approaches to problems. This journey of exploration has been documented as a series of experiments that we believe constitute a cohesive body of research. The research offers a framework for addressing many entrenched problems in fashion patternmaking with a series of tools and techniques for improving existing practises. Particularly, we include techniques that enable a new generation of “smart patterns” to be built, opening up many new creative possibilities.

An initial aim motivating the research was to map, as a series of flat patterns, the changing shape of the body as it moved. This addressed problems caused by trying to fit static patterns to constantly-changing body shapes. Our recording of body movement as a series of patterns allows the patternmaker to observe one pattern shape transforming into another, work that requires us to manipulate and analyse complex curved contours.

Since existing patternmaking systems are limited in their accuracy and lack the geometric precision needed to map body movement, our analysis of complex curved shapes seemed to require mathematics that was complicated and time-consuming to use. We further noted that the use of computer programs took patternmakers away from their drafting tables and slowed down their process. Our research thereby demanded a way to analyse and manipulate complex curved patterns with techniques that require the mathematical rigour of a computer program, yet are simple enough for patternmakers to use.

Our research also sought a more accurate system of patternmaking. Aiming to more precisely describe complex curved surfaces, we based it on principles of conics and Non-Euclidean geometry. Our techniques were further inspired by mathematical principles of calculus and Mnatsakanian's "Visual Calculus" techniques, which involve strategies to deconstruct complex curved shapes into simpler forms. We also of course used principles from Non-Euclidean geometry, demonstrating that surfaces of different shapes can have different curvatures, and that different curvatures have completely different geometric properties. We further showed how surfaces can have either flat or "Euclidean" geometry, "spherical" geometry or saddle-shaped or "hyperbolic" geometry. We found that darts made patterns more spherical in shape, while the addition of fullness and gussets made the geometry more hyperbolic in shape. Consequently, we explored dart manipulation techniques (experiment set 1) and techniques for manipulating fullness or "gusset manipulation" (experiment set 2).

Noting that contour patternmaking, as a process for manipulating patterns with curved contour lines, has limited accuracy in that it relies on the patternmaker to intervene with trial-and-error fittings, we showed that any complex curve or curved dart can be deconstructed into a series of darts and gussets at different apex points (experiment set 3 and 4). We made it clear that this new "contour manipulation" technique allowed patternmakers to analyse the structure and function of curved patterns, making it possible to easily manipulate complex curved contours while still maintaining the three-dimensional shape of the original garment. Here was a reliable mathematical process that did not require the patternmaker's judgement or intuition. We in effect proved that dart, gusset and contour manipulation provide key techniques to analyse the changing shape of the human body.

Further, the research showed how contour manipulation makes it possible to analyse the structure and function of complex curved shapes, and how complex asymmetrical darts and gussets can be analysed. Asymmetrical structures often create more apex points, allowing patternmakers greater control over their patterns (experiment set 5). Hence our research explored darts with exotic new forms such as "V" or heart-shapes (experiment set 10), and we then saw how contour manipulation allows the patternmaker to create extremely complex darts and still be able to precisely predict the three-dimensional forms they would create.

Explaining that the application of geometry to patternmaking had implications for many traditional patternmaking techniques, and that traditional techniques could be tested from a geometric point of view, we tested the geometric accuracy of techniques such as bust point dart manipulation using a series of mathematical experiments (experiment set 6 and 8). Traditional dart manipulation and contour tailoring techniques are supposed to move style lines around a pattern while keeping the original form of the garment. These techniques would often change the dart angle or move the apex locations on a pattern. Our research investigated the phenomenon and demonstrated that moving apexes or changing any dart or gusset angle in a pattern would change its three-dimensional form (experiment set 7). It showed that moving apexes usually changes the surface area, the three-dimensional form, and the volume that a pattern occupies – thereby challenging the accuracy of many existing patternmaking techniques.

Explaining that patternmakers still need to move apex points around the garment while maintaining a garment of a similar fit, the research posited new techniques that allow a patternmaker to move the location of an apex point while retaining the garment's surface area and volume. We applied geometric principles from conics, and shapes known as oblique cones to manipulate cones with greater precision, showing that such techniques could constitute alternatives to techniques such as bust point manipulation (experiment set 8).

Our research introduced concepts from Non-Euclidean geometry into fashion patternmaking in the light of one of the great limitations of existing techniques: the method whereby linear measurements are taken off the body and drafted into flat patterns. We saw plainly that from a geometric point of view this technique is limited in accuracy, as patternmakers use Euclidean mathematics to try to transpose curved (Non-Euclidean measurements) into flat patterns. We thereby explained why traditional techniques are only approximations, requiring the patternmaker to intervene with trial-and-error fittings.

Next, our research developed alternative techniques to linear measurements, reinventing traditional techniques using principles of Non-Euclidean geometry (experiment set 14). We noted the importance of understanding the curvature of a surface in so far as it determines the geometric properties of the pattern. We saw that both linear and angle measurements are required to determine the geometry of a surface, that devices such as the "drape measure" were invented to accurately take angled measurements off the body, that the drape measure could determine whether a surface was Euclidean, spherical or hyperbolic in its geometry, and that the tape measure alone was not capable of measuring the surface of the pattern. Our survey showed that these factors precipitated the reinvention many traditional approaches to patternmaking for the sake of greater accuracy.

We explained that the development of contour manipulation allowed complete mapping of body movement as a series of flat patterns (experiment set 15), and that body shape was measurable as a sequence of different flat patterns. The research mapped several of the most common body joints. It noted that even the wrinkles on a pattern can be mapped using contour manipulation to give critical information of how a pattern changes over time (experiment set 12). Mapping body movement using patterns allowed us to visualise the invisible phenomenon of movement, giving patternmakers the ability to analyse and understand movement and build clothing that better anticipates the changing shape of the body.

The research demonstrated that movement creates a much more complex view of the body, and how fashion technologists observe that every time a person breathes, eats or changes posture the shape of the body dramatically changes. Plainly, rather than a single static form the body is a constantly malleable shape. This fact led our research to question the existing paradigm of fit (experiment set 16), whereby static forms have limited ability to accommodate the constantly changing form. We saw that stretchable materials also did not solve all fitting problems and that more adaptive patterns need to be developed.

Our body of research sought to develop a new generation of patternmaking structures that can change shape over time. These “variable structures” were developed for patterns that move and constantly change shape (experiment set 17) whereby, anticipating body movement, they can be designed to interact in different ways. Further, garments can be designed to respond to different body movements and change shape accordingly. This introduced a new generation of patternmaking techniques such as “variable darts” and “wormholes” (experiment set 18) that create dynamic patterns to respond to body movement. Our research offered a series of techniques for building “smart patterns”, patterns capable of changing shape over time. We showed how traditional patterns are single static shapes while smart patterns can be designed to interact with different behaviours, and consequently how smart patterns are capable of building a new generation of garments with new functions and aesthetics.

Future applications for the research

Our research has created a body of work with vast implications for existing and future patternmaking. It sets out a conceptual framework for addressing many problems in the craft. It offers a systemic solution applicable to disciplines, from enhancing traditional techniques to developing new computer CAD applications. Indeed, new techniques make it possible to build a new generation of garments with “smart patterns” that introduce new creative possibilities and applications. Above all, we have demonstrated that there are multiple avenues of research that should be explored in the future.

Smarter, more creative patternmakers

Our research constructs a series of techniques that will empower fashion designers and patternmakers. For example, the ability to manipulate curved Non-Euclidean surfaces with techniques based on Non-Euclidean geometry lets patternmakers solve traditional problems in new ways, so that contour manipulation allows patternmakers to describe complex curved shapes as a series of darts and gussets. We have worked to offer patternmakers more precise control over their patternmaking, while understanding how movements change patterns over time allows them to make more informed decisions.

The research also introduces many new and detailed terms that allow different patternmaking phenomena to be described with greater accuracy, pace and efficiency. Geometric principles of the patternmaking system use terms similar to mathematical geometry, making it easier to communicate core concepts to mathematicians, scientists or engineers who may want to develop technology in this area. We now see that geometry is the universal language for communication between the disciplines.

Existing techniques improved

The body of research offers techniques that increase patternmaking accuracy by introducing concepts from Non-Euclidean geometry. For example, the measurement of curvature and geodesics addresses many of the limitations of drafting patterns from linear measurements, and dart, gusset and contour manipulation allow patternmakers to analyse and manipulate complex contour patterns with geometric accuracy. Patternmakers can create style lines with complex shapes on complex contours using contour manipulation, as well as building intricate curved shapes. There is no question that Non-Euclidean geometry offers an alternative paradigm to traditional patternmaking techniques, allowing patternmakers to question how and why existing techniques work and what makes them effective.

Educational benefits

We have demonstrated that Non-Euclidean patternmaking techniques offer benefits for education, in that they can be taught as a set of mathematical concepts, and that each fitting can be addressed as a geometric problem instead of a rote-learned set of procedures. Clearly, using geometry puts less reliance on intuition or judgement and more on a patternmaker's ability to solve problems. This also makes learning patternmaking easier for beginners, and provides a technique for patternmakers who are already skilled at mathematics, akin to engineers and scientists. Experienced patternmakers also benefit since they can focus their attention on important aspects such as garment aesthetics.

We have asserted that Non-Euclidean patternmaking can be an accessible way to introduce sophisticated mathematics to people who dislike traditional mathematical education. Certainly, the tactile craft of patternmaking engages people who may shrink from numbers and symbolic representation. We have seen how mathematicians such as Taimina (2009) demonstrated the accessibility of Non-Euclidean geometry to a new audience, and how Non-Euclidean patternmaking extends this to engage an even wider range of people interested in fashion and textiles.

Mapping and anticipating body movement

The thesis shows how the ability to anticipate body movement in patterns introduces a new dimension of time and movement into patternmaking, so that a patternmaker can now control how a garment will change over time and measure the wearer's range of motion rather than a single static shape. This knowledge can be used to make subtle informed alterations to patterns. Alternatively, we saw that a patternmaker may radically re-design a garment's movement for functional or aesthetic purposes, offering patternmakers more control over their designs than ever before.

Variable structures

Variable structures, as a new generation of patterns designed for movement and interactivity creating dynamic structures instead of static patterns, offer many different applications, including improving the comfort of a garment by improving its fit under conditions of constant change. In ready to wear clothing variable structures allow a single garment to fit a wider range of body shapes than a garment that fits a single static shape. We have thus demonstrated that variable structures can enhance tailoring techniques, as well as offer a unique aesthetic. The pattern may dynamically change shape and not rely on material stretching to create movement. Such smart patterns would avoid stretching or wrinkling material as static patterns do, engendering a new aesthetic in tailoring whereby precisely mapping movement and manipulating variable structures promote precision tailoring at a new level of sophistication.

Function and interactivity

We have asserted that variable structures can also be designed to suit diverse functions and to behave in different ways. Our experiments demonstrate concepts for garments that can be built for both function and aesthetic purpose. In one example, in order to offer the greatest mobility the hem of a skirt slowly elevates as the wearer starts to walk faster then lowers as the wearer's speed decreases (experiment 68). Hence we serve a purely functional purpose, yet also design movement into garments for aesthetic purpose. For example, a garment that changes shape as the wearer walks, exaggerates the body shape, accentuating the wearer's femininity or masculinity.

New aesthetics

Our research lists many techniques that offer creative possibilities. Patternmakers can create complex curved patterns with greater precision than ever before, can map and manipulate body movement, and build clothing with variable structures that change shape and behaviour over time. We demonstrate that there is no shortage of opportunities for designers to discover and express new aesthetics.

Technology applications

Our research and application of Non-Euclidean geometry enables new approaches to building computer algorithms that draft patterns around three-dimensional body scans, addressing limitations in accuracy due to reliance on the judgement of the patternmaker. Measuring the body with geodesics and recording the curvature of the surface ensures more accurate measurements, just as the introduction of contour manipulations makes manipulating complex curved patterns easier. Our research bridges the gap between traditional techniques and the evolving needs of fashion technologists. The application of Non-Euclidean principles makes it easier to translate complex 3D measurements into accurate flat patterns. Further, computer scientists and patternmakers can communicate in the universal language of geometry to form much more sophisticated garment-fitting approaches.

Our research embraces technologies that sell clothing by means of websites and smart phones, since the growth of online clothing sales highlights the need to fit clothing without physically testing products. Indeed, there are business models that require the buyer to measure their own body using linear measurements and enter the information onto a website. There is software that extrapolates measurements from a body by taking a series of photos at different angles, aiming to take linear measurements and match them to clothing size. This has the potential to create custom-fitted clothing and to check the fit. Such measurements, while they rely on linear measurements and are based on paradigms of Euclidean geometry, have limited accuracy and do not guarantee the best fit. Applying Non-Euclidean patternmaking can enhance the accuracy of patterns developed for these business models. For example, Non-Euclidean patternmaking could specifically design styles that incorporate the curvature of geodesics to best employ measurements taken from a photograph or 3D scan.

The research also offers applications in relation to the hi-tech materials of shape memory alloys or shape memory polymers. These materials change shape over time when subject to heat or electric current. Although at present they are unresponsive, energy intensive and unreliable, technologists anticipate that in the future these materials will become inexpensive, reliable and commonplace (Lee 2007 p. 116). Insight gained by mapping body movement and from designing variable structures, could be easily applied to future shape memory alloys and polymers.

Future research

In setting up a conceptual framework for improving diverse areas of fashion patternmaking, our research should certainly be tested in multiple areas of the fashion industry. Our techniques can be employed to make exotic new patterns in high-end designer clothing, as well as to improve the efficiency of techniques in ready to wear clothing. Techniques such as variable structures can be used to create garments that fit a wider range of sizes, and improve the fit of ready to wear. Variable structures as concepts are still in their infancy and could be vastly improved by being applied to different designs, as could their execution by using a combination of different materials to improve their finesse. The geometric nature of Non-Euclidean patternmaking also facilitates communication with fashion technologists to develop hi-tech applications. These can be applied to algorithms that turn 3D scans into flat patterns, helping internet shoppers test whether clothing is going to fit. Our research has aimed to generate a suite of new techniques that allow patternmakers new creative possibilities. In sum, the mapping of body movement and "smart patterns" introduces new creative opportunities to build a new generation of fashion designs.

Conclusion

This thesis demonstrates that the application of geometry to fashion patternmaking has strong potential to improve many areas of the fashion industry. Geometry offers a way to explain the limitations of traditional techniques while introducing concepts from Non-Euclidean geometry to bypass them. New techniques based on Non-Euclidean principles undoubtedly give patternmakers accuracy and creative freedom. Since patternmaking is so essential, these concepts will pervade the entire industry, with applications from high fashion to fast fashion. This will have commercial benefit, as time, labour and materials are conserved by using more efficient techniques. Patternmaking has changed very little in the last hundred years, so that such new techniques will be an influential source of novelty and enable creative expression. Indeed, the popularisation of a single new technique can often establish a designer's signature style. Our thesis offers multiple techniques to choose from.

We have amply demonstrated that the introduction of mathematical concepts enhances patternmaking and brings new possibilities. The ability to map movement using patterns and to anticipate body movement introduces a new dimension of time, while variable structures and smart patterns make it possible to build a new generation of moving garments with new fit, functions and aesthetics. Patternmaking systems based on geometry allow us to integrate new technologies such as computer algorithms that fit garments using 3D body scans. This may well enable clothing to be fitted remotely, offering new possibilities for internet shopping and new business models. In sum, the fashion patternmaker is empowered to be a smarter designer, with methods grounded in mathematical rigour. A geometry-based patternmaking system allows the practitioner to focus on what they do best, to express their fashion creativity in new and exciting ways.

GLOSSARY

NEW FASHION PATTERMAKING TERMS	
Asymmetrical darts	Darts with asymmetrical dart legs.
Behaviour	The way a garment with variable structures functions and interacts when movement is applied.
Bend joint	A joint that bends over time and changes shape.
Branching darts	Darts that branch into a sequence of smaller darts.
Close-ended darts	Darts with their ends sewn together.
Complex darts	Darts with more than one apex point shaping the garment.
Complex gusset	A gusset with multiple apex points.
Concave curve	The edges of two piece of material that join together to create a convex shape.
Concave dart	A dart with a concave shape.
Concave gusset	A gusset with a concave shape.
Cone angle	The angle of the cone at a point. This can be the dart angle if the surface is spherical, or a gusset angle if the shape is hyperbolic.
Cone point	The tip of a cone.
Cone tips	The tip of a cone cut off a larger cone.
Contour manipulation	A technique that manipulates the location of a style line while maintaining the original pattern shape.
Control point	Points on variable structures that can be used to control its size and shape.
Convex curve	The edges of two pieces of material that join to create a convex shape.
Convex dart	A dart with a convex shape.
Convex gusset	A gusset with a convex shape.
Curved dart	A dart with a curved dart leg.
Diamond dart	A diamond-shaped dart that creates the effect of a gusset and several

	darts.
Drape measure	A device that interprets the curvature of a flat or curved surface into a cone measurement.
Dynamic pattern	A pattern designed to change shape over time, anticipating body movement.
Floating plate	A patternmaking structure designed to float on the surface of a garment and constantly change shape to accommodate movement.
Geometry-based patternmaking	A patternmaking system based on principles of modern geometry.
Gusset angles	The interior angles of a gusset.
Gusset leg	The edges of the side of a gusset that converge at its apex.
Gusset length	The length of the edge of a gusset.
Gusset manipulation	A technique that moves style lines of gussets around a garment while maintaining the garment's three-dimensional shape. This is analogous to dart manipulation for gussets only.
Heart dart	A heart-shaped dart that creates the effect of a series of darts and gussets.
Input	A change of shape such as body movement, or output of other variable structures that moves the position of a control point.
Network	A series of variable structures combined to give a garment certain behaviour.
Open-ended darts	Darts with their ends left open and not joined.
Output	The resulting change in garment shape caused when a garment's control point is moved.
Piston	A patternmaking structure that holds elastic tension, that can be used to control variable structures.
Re-shaping contours	The process of re-drawing the shape of contour patterns.
Rigid measurements	Measurements in triangular grids that are rigid and cannot pivot or slide out of shape.
Rotational joints	A joint that rotates around a single point.
Series –	Multiple patterns that describe a three-dimensional shape changing

Sequence of patterns	shape over time.
Simple darts	Darts with a single apex point shaping the garment.
Singularities	A structure where a tube connects to a flat piece of material, allowing a large surface area of fabric to occupy a small point on a two-dimensional surface.
Smart garment	Garments with patterns designed to change shape over time for different forms, functions and aesthetics.
Smart pattern	A pattern designed to change shape in time.
State – Key frame - Frame	The shape of a pattern at a point in time.
Static pattern	A pattern designed to fit a single static shape.
Symmetrical darts	Darts that have symmetrical dart legs.
Three-point – Four-point diamond dart	A dart with three to four points that create the effect of a gusset and several darts.
Total gusset angles	The total of gusset angles in one or more gussets.
Variable darts	Darts that are designed to change shape over time.
Variable structures	Patternmaking structures that can change shape in time to create different functional or aesthetic effects on a garment.
"V" shaped darts	Darts of a "V" shape that create the effect of a series of darts and gussets.
Wormholes	A structure created by joining two singularities to manipulate the garment shape to create different functions and effects.
Wrinkle analysis	The process of analysing wrinkle shapes, to understand their structure and function.
MATHEMATICAL TERMS	
3D Scan	A three-dimensional shape recorded as digital information.
3D Scanners	Electronic devices that capture the three-dimensional form of the body as digital information.
4D Scan	A sequence of 3D scans recorded over time.
Angles at a single point	The number of angles measured at a single point.

Angles in a triangle	The sum of the interior angles in a triangle drawn on a surface.
Angle measurements	A measurement the total angles in a revolution at a point on a surface.
Axioms	The assumptions that mathematical logic is built on.
CAD software	Computer-aided design software.
Calculus	The branch of mathematics that allows calculation of changing quantities through differentiation and integration.
Conical cross-sections	Different shapes created by cutting a flat plane through a cone at different angles.
Cross-section	The shape of a surface created by cutting a straight plane through an object.
Deconstruct	To analyse, divide into component parts, seek origin.
Differential calculus	The branch of calculus that allows the slope of curves ("derivative") to be calculated.
Elliptical cross-section	A plane cut through a cone to reveal an elliptical shape.
Euclid	The ancient Greek author of the book *Element*s, that contains fundamental rules of geometric mathematics.
Euclidean geometry	The branch of mathematics that describes flat "Euclidean" surfaces.
Flat plane	A flat two-dimensional surface.
Frustum	A conical prism, the shape of a cone with its tip cut off.
Generator	A mathematical term for "straight lines that go through the cone point or parallel to the axis of the cylinder" (Taimina 2005, p. 48).
Geodesic	The shortest distance between two points on a surface.
Geometry	The mathematics of points, lines, surfaces, solids and higher dimensional analogues.
Great circle	A circle with the widest diameter on a sphere.
Hyperbolic geometry	The geometry of curved saddle-shaped surfaces. A point on a hyperbolic surface has more than 360° in a revolution.
Integral calculus	The branch of calculus that allows the area under a curve or "integral" to be measured.
Irrational numbers	A number that cannot be represented as a ratio of two integers.
Mathematical proof	A mathematical argument based on axioms, reasoned through

	deductive logic.
Non-Euclidean geometry	The branch of mathematics that describes three-dimensional curved surfaces, including spherical and hyperbolic geometry.
Oblique cone	A cone with the cone line moved away from the centre of its base.
Origami	The art of paper-folding.
Origamics	The scientific study of Origami and its mathematical principles.
Parallel postulate - Euclid's 5^{th} postulate	The idea that only one parallel line can pass through a single point on a surface. "If a transversal (line) falls on two lines in such a way that the interior angles on one side of the transversal are less than two right angles, then the lines meet on that side on which the angles are less than two right angles" (Tabak 2004, p. 28).
Playfair's postulate	A simplification of Euclid's fifth postulate, developed by John Playfair.
Rational trigonometry	A branch of mathematics developed by Dr Norman Wildberger that allows trigonometry to be calculated without the use of irrational or transcendental numbers.
Right cone	A cone with the cone tip at right angles to the base.
Rigour	An idea based on a logically-reasoned argument (Eg: sheet metal artisans who shape flat metal sheets into complex shapes).
Spherical geometry	The geometry of curved spherical shaped surfaces. A point on an elliptical surface will have less than 360° in a revolution.
Symbolic representation	Representation of mathematical concepts as symbols.
Tangent line	A line that touches a curve or solid at one point.
Theorem	A mathematical argument based on logical reasoning.
Transcendental numbers	Non-algebraic numbers such as π or e.
Triangulation	The process of dividing a complex shape into a series of smaller triangles to aid calculation.
Trigonometry	The branch of mathematics dealing with sides and angles of triangles.
Treemaker	A computer program created by Robert Lang using mathematical principles to help create more sophisticated origami.
Visual calculus	A form of mathematics developed by Mamikon Mnatsakanian that demonstrates calculus proofs with visual diagrams and physical models.

FASHION TERMS	
Anthropometrics	The science to taking and analysing body measurements.
Apex	The tip of a dart or gusset.
Basic block	A block pattern that can be altered to create different designs.
Bespoke tailoring	Highly-skilled tailoring of exquisite quality, custom-fitted to the client.
Bias	The direction diagonal to the weave of the fabric.
Bias cutting	A technique where fabric is draped on the bias in order to make it more flexible, and to drape in a different form.
Blending	"A process of smoothing, shaping, and rounding angular lines along a seam for a smooth transition from one point to the next and for blending marks made on the pattern or muslin." (Armstrong 2010, p. 11).
Block pattern	A pattern that can be manipulated into different designs while maintaining a similar fit.
Bust point	The fullest part of the tip of the bust.
Bust point manipulation	The technique of manipulating the location of the dart apex at bust point.
Contours	Patterns created by joining together two or more pieces of fabric with shaped edges to create a curved three-dimensional form.
Crochet	The process of creating textile from interlocking loops of yarn, often using a crochet hook.
Dart angle	The angle of the dart.
Dart leg	The seam lines that converge at a point to form a dart.
Dart manipulation	The process of moving the location of a dart around the garment while retaining the garment's original fit.
Drafted pattern	A pattern drafted from body measurements into a flat pattern.
Drape patternmaking	A technique of making patterns by draping fabric on the body and recording the shapes as flat patterns.
Ease	Additional material added to a pattern so that the wearer can move and breathe with comfort.

Fashion patternmakers	People who make garments from shaped pieces of material.
Fashion technologists	Experts who create, develop and maintain the technology used in fashion production.
Fast fashion	A business model of mass-produced fashion garments made at an extremely fast speed.
Fit	The ability to fit to the body.
Haute couture	High fashion. The art form of highly skilled, custom-fitted fashion for an exclusive clientele.
Measurement taker	Device used for taking measurements before the invention of the tape measure.
Mirror symmetry - Reflectional symmetry	A shape that is the same form as a reflected copy of itself.
Moving apex	The process of moving the apex point in a pattern.
Negative ease	Patterns made from stretch materials that are reduced in size to anticipate the garment stretch on the body.
Null fitting – Anti-fit garments	Garments designed to accommodate a wide range of body shapes.
Patternmaking	The art form of creating three-dimensional garments from flat two dimensional pieces of material.
Patternmaking system	A methodology of drafting patterns.
Rock of eye	The skill, judgement and accumulated experience that allows a patternmaker to draft a pattern from intuition.
Rotational symmetry	A shape that can be rotated around a point and retain the exact same form.
Ready to wear	Mass-manufactured garments made to fit a standard size.
Scaling - Grading	The process by which a garment can be scaled, using a formula, into different sizes.
Shape memory alloy– Shape memory polymer– Electro-active polymer.	Fibre types that can change shape when heat or an electrical current is passed through them.
Sizing systems	A system of sizes devised to fit ready to wear clothing to parts of the

	population with diverse body shapes.
Stretch material	A material with flexible properties that can stretch in size.
Style line	A seam line used in a garment as a design feature.
Tailoring	Clothing made to fit the client by means of body measurements and iterative fittings.
Tape measure	A device with standardised markings on it used to take linear measurements.
Total dart angles	The sum of the total dart angles at a single apex point.
Trial-and-error fittings	The process of fitting garments by repeated alterations until a desirable pattern is drafted.
Truing	"The blending and straightening of pencil lines, crossmarks, and dot marks for the purpose of establishing correct seam lengths" (Armstrong 2010, p. 10).

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