MEASUREMENT OF FABRIC DRAPE USING A MODIFIED DRAPEMETER

by

Sara L. Herbert

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APPROVED:

Carolyn L. Moore, Chairman
Department of Clothing
and Textiles

Rinn M. Cloud
Department of Clothing
and Textiles

Charles F. Reinholtz
Department of Mechanical
Engineering

Marvin Lentner
Department of Statistics

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Chairman, Carolyn L. Moore
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(ABSTRACT)

The original goal of this research was to produce a user friendly program that could simulate fabric drape on a manikin through computer graphics. This graphics program operates with a data base of fabric properties in order to create draped fabric shapes for a variety of fabrics as they would form a garment on the human body (Dhande, Rao, Tavakkoli, and Moore, 1993).

A modification of the Fabric Research Laboratories (FRL) Drapemeter was developed with interchangeable pedestals and platform disks in order to investigate the effects of drape overhang length and different platform shapes and radii of edges on the node counts and drape values of two medium weight woven apparel fabrics and to provide a means for collecting data needed for the graphics program. Specimens were cut from two medium weight fabrics into circles with 10, 14, and 18 inch diameters and ovals with 10 X 11 and 18 X 19 inch diameters. Statistical analysis indicated that the modified drapemeter measures fabric drape as accurately as the FRL drapemeter; therefore, the modified drapemeter was found to be reliable for measuring drape. ANOVA factorial analysis revealed that pedestal height can be altered without concern for precision in drape measurement. Drape coefficients were found to be significantly affected by fabric drape overhang length. Statistical analysis also indicated a significant relationship between platform shapes and drape coefficients. Drape coefficients for platform edge radii were found to be significantly different but without a linear relationship.

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CHAPTER 1: INTRODUCTION

More than any other characteristic, drape distinguishes textile fabrics from other nonflexible materials or slightly flexible materials such as steel, paper, or foam rubber (Merkel, 1991). Textiles made from the same fibers can differ in yarn composition, yarn count, ratio of warp count to weft count, yarn spacing, fabrication method, and finish. The many variables of a textile's geometry create the special problems in obtaining objective measurements of its fabric drape. Drape measurement of a textile is dependent on how the fabric geometry interacts to produce folds. When a textile hangs from a support surface, the textile will form into a series of double curves or folds. The more flexible the textile, the more folds the textile will form. The depth of a draped textile's folds and the ability of a textile to form these folds relates to the textile's physical and mechanical properties. Physical and mechanical properties affecting fabric drape are flexibility, compressibility, extensibility, resilience, density, surface contour, bending, buckling, shearing, and weight (Joseph, 1986).

The drape of a textile is one of the most important factors which influence the acceptance of the textile for a specific end-use by the consumer. Fabric drape is a prime component of fabric hand, and fabric hand affects the aesthetic appeal of any textile. Thus, how a fabric drapes as it composes garments has long been a concern of apparel designers. For example, a very flexible or limp fabric with considerable drape hangs flat or close to the underlying body minimizing any change in appearance; while a garment of a much stiffer fabric may add several inches to the appearance of the body. Stamper, Sharp, and Donnell (1986) found even when fully gathered or pleated, a limp, very drapable fabric would cling more closely to the underlying body than does a very stiff fabric when constructed in a very tailored, streamlined design.

Traditionally, apparel designers have intuitively and subjectively assessed the drape of fabrics used in the design of a garment. The subjective judgements of fabric drape by apparel designers are dependent on the preconceptions of a variety of personalities which may or may not form judgements similar to consumer judgements and demands. Since the draping quality of a fabric is one of the most important considerations in selecting a textile to achieve the desired aesthetic effect in a garment design, there is a need to evaluate fabric drape objectively (Brand, 1964). In order to obtain objective evaluations of fabric drape, researchers have related the drape of textile fabrics to their measurable physical and mechanical properties (Amirbayat & Hearle, 1989; Postle & Postle, 1992, 1993). Other researchers have developed drape testing apparatus such as the Fabric Research Laboratories (FRL) drapemeter (Chu, Cummings, & Teixeira, 1950; Collier, Collier, Scarberry & Swearingen, 1988; Cusick, 1968;). Results obtained from fabric experiments with these drape testers have consistently been related to measurable physical and mechanical properties of fabrics (Collier, 1991; Collier, Paulins, & Collier, 1989; Cusick, 1965; Dowlen, 1976; Gaucher, King, & Johnston, 1983; Sudnick, 1972). Yet, apparel designers continue to resist objective drape testing methods because instruments needed to obtain objective evaluations are cost prohibitive and resulting data require time consuming mathematical calculations and statistical analysis in order to gain anything meaningful.

Apparel designers use subjective fabric drape evaluations while using the fabric drape method for patternmaking. Often the way a fabric falls around the human body determines how the garment design will develop (Jaffe & Relis, 1973). Fabric drape is one of the most important considerations in selecting a fabric to achieve the desired garment mobility as well as desired aesthetic effect. An example is the importance of fabric drape in dance costumes. A floating, very drapable fabric such as chiffon enhances the rhythm and movement of the dancer's body, while the ballerina's tutu of stiff tulle and net communicates a more formal dance setting and garment design (Stamper et al., 1986). In the flat pattern method of patternmaking, fabric drape must also be considered. The design lines must relate to the natural fabric drape. A style prototype must be cut from the fabric and assembled before a pattern can be checked and subjective evaluation is complete (Collier, 1990). If a fabric choice is not appropriate for a new pattern, then the designer has incurred an expensive mistake. Cusick (1962, cited in Hearle, 1969) and Collier (1991) found that current fashion trends also influence what consumers consider acceptable fabric drape for a particular garment design. Fabric drape is very difficult to assess subjectively.

A goal of the apparel industry is to develop a complete computer integrated manufacturing (CIM) process. The CIM process will enable apparel manufacturers to service customers more quickly and reduce storage of inventory (Harlock, 1989; Jayaraman, 1990). The apparel design phase continues as a gap in CIM systems and continues as a need for further research (Harlock, 1989; Shishoo, 1990a, 1990b). Many of the apparel design processes, such as fashion illustration, pattern drafting, flat-pattern methodology, pattern size grading, and marker generation have been introduced to apparel designers as computer graphic programs. Some of these computer graphic simulation programs will integrate with other computerized apparel manufacturing processes (Jacobs-Blecha & Riall, 1991; Kosh, 1990; Lee & Steer, 1991; Waddell, 1992). The fabric drape method for patternmaking needs to be developed in order to close the gap in creating a complete CIM system for apparel manufacturers (Collier & Collier, 1990). In order to develop a computer program for graphic simulation of patternmaking by the fabric drape method, a computer program for graphic simulation of fabric drape must be developed.

The ability to computer simulate the compound curvature in surfaces of fabrics draped on the human body is a vital step toward providing the designer with a user friendly computer program with a data base containing drape information for a variety of fabrics. Since apparel designers are currently using computer graphic simulation programs as design tools, such a program will provide a useful means for obtaining objective fabric drape information.

As an approach to development of a computer graphic program for simulating fabric drape several researchers have related fabric mechanical properties to fabric formability and to the draping method of apparel design (Basset & Postle, 1990; Deschamps & Ceith, 1985; Heisey & Haller, 1988; Lindberg, Behre, & Dahlberg, 1961; Shishoo, 1990b). Textiles are different from other materials because they are flexible. Apparel designers achieve style success because fabrics buckle or drape into folds. Creative and detailed placement of fabric folds contribute apparel comfort and aesthetic appearance (Amirbayat & Hearle, 1989). Lindberg, Waesterberg, and Svenson (1960) found that fabric buckling is dependent on the radius of curvature of the fabric's support surface and the length of the fabric sample. Shinohara, Ni, and Takatera (1991a, 1991b) found a variety of fabric buckling patterns. Some knit fabrics were found to fold similar to a bellows, where as tested woven fabrics were found to form different lobe patterns (Shinohara et al., 1991a, 1991b).

Other studies have developed methods for computer simulated fabric draping. Nishikawa, Niwaya, Shibuya, and Aisaka (1987) used a technique involving an ultrasonic sensor to make noncontact measurements of fabric drape in shirts to obtain data for creating a computer graphic display of the shirts. One softwear producer has developed computer graphic simulations which allow the designer to produce fashion illustrations of varying fabric prints mapped on a rotating mesh human body (Harlock, 1989). Other computer program developers use finite element techniques common to computer aided design (CAD) systems employed by mechanical and civil engineers. Finite element techniques are suitable for predicting small deformations of materials subjected to a known load; but these techniques are not always applicable to textile materials which normally exhibit large deformations under relatively low forces (Harlock, 1989). Dhande, Rao, Tavakkoli, and Moore (1993) developed a model using intrinsic geometry to predict fabric deformation. The intrinsic geometry model provided a base for the development of a computer graphic simulation program which predicts and depicts fabric drape. Their computer simulation project focuses on the use of intrinsic geometric parameters and fabric mechanical properties as inputs for simulating fabric drape (Dhande et al., 1993). Previous studies have not used fabric property measurements as variables in computer simulation of fabric drape.

In order to continue research with geometric modelling of fabric drape on a variety of surfaces, Dhande et al. (1993) stated a need to compare photographs obtained from drapemeter experiments with fabrics draped on a variety of surfaces representative of the human body to their computer graphic simulations. Dhande et al. (1993) also stated a need to compare resultant computer graphic simulations with photographs obtained from drape tested fabric samples with overhang lengths greater than those of standard drape testing protocol. Thus, there is a need to construct a drape testing apparatus that could provide comparison objective measurements and needed photographs for continuing the research of Dhande et al. (1993).

In working towards the development of a computer simulated model for demonstrating fabrics draped on a three-dimensional human figure, more information regarding how different fabrics drape is needed. Since a variety of support geometries occur on the body and a variety of fabric overhang lengths occur in a garment, there is a need for a fabric drape testing apparatus (such as a drapemeter) that could measure fabrics of varying overhang lengths supported by platforms of various shapes and sizes. Measurements from such a modified drapemeter could be used along with other mechanical property values of fabrics to provide data upon which a computer simulation model such as the one developed by Dhande et al. (1993) could be based. These measurements may successfully predict fabric drape from different body areas such as the shoulder, waist, and neckline using a variety of fabrics.

The purpose of this study was to develop a modification of the FRL drapemeter with interchangeable pedestals and platforms in order to investigate the effects of fabric overhang length, platform disk shape, and edge radii on the drape values of woven apparel fabrics. Modification of the FRL drapemeter was a segment of ongoing research involving the development of a computer simulation model which uses intrinsic geometry parameters and fabric mechanical properties for simulating the draping of fabrics on a three-dimensional human form (Dhande et al., 1993).

A modified drapemeter was built based on the drapemeter developed by Fabric Research Laboratories which uses a circular platform with a perpendicular side or edge for measuring fabric drape. The modified version has oval as well as circular platforms that have edges with varied radii of curvature allowing the fabric to drape in a pattern more closely resembling the curves of the human body. The modified drapemeter also has four pedestals of different heights to support the platforms that allow for larger than traditional specimens to be measured. Independent variables included drape overhang length and platform shape and edge radii. Dependent variables included drape diagram weight differences, node counts, and drape coefficients or drape values. Two plain weave fabrics that exemplified mid-range drape coefficients were used to measure the effects of variables. Fifteen cardboard circles were used to compare the accuracy of the modified drapemeter to the FRL drapemeter.

Computer simulation of fabric drape using geometric modelling has potential benefits for the apparel manufacturing industry (Dhande et al., 1993). Costs to make up prototypes could be drastically cut or eliminated. Savings in time and costs in the design department would allow creative personnel to generate more designs with more fabric possibilities without actually purchasing fabric for draping or sample making. Potential cost benefits increase when a successful design can be simulated in a different fabric weight and/or texture for a different season without having to make trial samples from the proposed fabrics. This type of computer program would also facilitate computer integrated manufacturing and the implementation of quick response strategies.

CHAPTER 2: REVIEW OF LITERATURE

This chapter reviews literature concerning fabric drape and methods for assessing drape. Research on drape assessment generally follows one of two directions. The first has been to subjectively and objectively assess fabric drape in relation to the aesthetic appeal of fabric and its end use. The second has been to theoretically analyze the fabric properties that affect drape in order to understand drape phenomena and to generate information useful for fabric engineering (Moore, Dhande, & Tavakkoli, 1990). Established research in both areas is addressed by this paper. This review of literature concentrates on how drape is defined, fabric properties influencing drape, subjective and objective methods of assessing drape, and implications of drape assessment.

Fabric Drape

Definition

Neither the American Society for Testing and Materials (ASTM) nor the American Association of Textile Chemists and Colorists (AATCC) has developed a consensus definition for drape. Without a consensus definition, researchers must define drape as they understand it. Many researchers have attempted to define drape in terms of different properties of fabrics, such as flexibility (Chu et al., 1950; Hearle, 1969; Wingate, 1979). Chu et al. (1950) define drape as a property of a textile material "which allows a fabric to orient itself into graceful folds or pleats when acted upon by the force of gravity" (p.539). This definition is very similar to the one that Wingate published in 1979 in Fairchild's Dictionary of Textiles. Wingate (1979) defines drape as "a characteristic of fabric indicative of flexibility and suppleness used with reference to the way a fabric falls when hung or arranged in different positions" (p.201). Researchers indicate that the flexibility characteristic of drape, more than any other characteristic, distinguishes textile fabrics from other nonflexible materials or slightly flexible materials such as paper or foam rubber (Chu, et al., 1950; Hearle, 1969; Merkel, 1991; Wingate, 1979).

Other researchers define drape based on the deformation of the fabric when hanging under its own weight (Collier, Collier, O'Toole, & Sargand, 1991; Cusick, 1965; Gaucher et al., 1983; Merkel, 1991; Moore et al., 1990; Sudnik, 1972). By emphasizing the deformation that occurs when a portion of fabric is supported as would be in the wearing of a garment or during drape testing, Sudnik (1972) defines drape as a multi-dimensional fabric property determined by "the extent to which a fabric will deform when it is allowed to hang under its own weight" (p.14). It is possible for a fabric to undergo deformations of various types and in many directions. "Deformation occurs by slippage at the weaker points between molecules rather than by the breaking of intramolecular bonds" (Van Vlack, 1964, p.189). Unlike many other materials, fabric is planar; thus, the analysis of fabric deformation is a two-dimensional problem (Collier, 1991). Key to each of these definitions is that a portion of the fabric is supported as it would be if the fabric was draped from an area of the human body or a drape tester. For the purposes of this study fabric drape will be defined as the extent to which the unsupported portion of a fabric will deform when allowed to hang under its own weight (Hearle, 1969; Sudnik, 1972).

Gravitational Influence

By definition drape is influenced by the manner in which a fabric reacts to the force of gravity. Newton's law of universal gravity states "Every mass in the universe attracts every other mass with a force that for two masses is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them" (Hewitt, 1989, p.156). The intensity of gravity is inversely related to the square of the distance from its cause (Hewitt, 1989). As fabric specimen size increases, the unsupported portion of the specimen increases if the support platform remains the same. The unsupported portion of a fabric specimen is the drape overhang. Gravity would have a greater influence on fabric drape for increased specimen sizes if they are draped on support platforms of equal size.

Two factors that affect the drape of a fabric are weight (mass) and stiffness. The mass of a fabric reacts to the force of gravitational pull causing an unsupported portion of fabric to drape. The stiffness of a fabric exerts the resistance to gravitational pull of the earth. Flexural rigidity of fabric, which is calculated from a fabric's weight and bending length, has been correlated by researchers to fabric drape coefficients and values (Cusick, 1965; Dowlen, 1976; Sudnik, 1972).

In 1986, Hearle and Amirbayat studied fabric drape of four textiles (characterized by fabrication method: plain weave, twill weave, weft knit, and stitch bonded) cut into circles of three different diameters (36cm, 30cm, 24cm). Each specimen was draped over a circular pedestal measuring 18cm in diameter. Results indicated that the drape coefficients decrease as specimen size increases; the greater a textile's bending resistance, the shorter the overhang length; and the heavier the fabric, the further a fabric will hang. Hearle and Amirbayat (1986) attributed results to increasing gravitational potential energy relative to a textile's bending energy.

Implications of Drape in Garments

Drape is one fabric property that affects the design and silhouette of a garment. Human bodies cannot be upholstered with fabric as would be a nonmobile chair or sofa. Since humans must move in their clothing, apparel designs must include extra fabric or special stretch fabrics in areas of movable body parts. Design functional ease is the extra fabric incorporated into many garments in order to accommodate body motion. Pleats or gathers between the skirt waist and hips allow extra fabric area for the body to sit. Gussets are extra fabric sections sewn in garment areas in order to obtain maximum movement. Flared bottom skirts allow extra fabric room to accommodate walking. Additional fabric ease is included in some apparel parts for aesthetic purposes. Examples of aesthetic ease include puff sleeves, ruffles, and bubble skirts. Design (functional and/or aesthetic) ease creates a width of the fabric that is greater than the width of the support it falls over. In other words, part of the fabric is supported and part of the fabric is unsupported by the body as it forms the drape of a garment. Apparel designs which exemplify this effect of ease include flared skirts and circular skirts, butterfly sleeves, capes, and flounces.

When fabric is partially supported by a surface it bends as it reacts to gravity near the edge of the surface. Fabric drape is highly correlated with fabric bending length which is influenced by fabric weight (Brown, Buchanan & Clapp, 1990; Dowlen, 1976; Gaucher et al., 1983; Ghosh, Batra & Barker, 1990a, 1990b, 1990c; Hearle, 1969; Lindberg et al., 1960). When a fabric specimen or a garment is partially supported by a surface which is much smaller than the specimen or garment, then the specimen or garment undergoes double curvature. The resistance of the fabric to distortion as it falls (bends) from a support is related to the change in the angle between the yarns, and the ease with which the fabric may be extended. When the angle between warp and filling yarns of a woven fabric is altered, shearing occurs. Cusick (1965) found correlation between shear stiffness measurements and drape coefficients of fabrics.

Fabric Properties Influencing Drape

Many of the physical and mechanical properties of a fabric affect its drape. Some of these properties include the flexibility, compressibility, extensibility, resilience, density, surface contour, bending, buckling, shearing, and weight of the fabric (Joseph, 1986). Another aspect or characteristic of fabric which contributes to its drapeability is fabric geometry. The three factors which influence the drapeability of fabric addressed by this review of literature are fabric geometry, bending, and shear.

Objective methods of measuring fabric properties related to drape involve calculating the flexural and shear rigidity of the fabric. Flexural rigidity is equal to the bending length cubed multiplied by the fabric weight per unit area (ASTM D 1388). Shear rigidity is determined by the resistance of the fabric specimen to a change in the angle between the warp and weft yarns. Cusick (1961) found that shear rigidity relates to the area under the curve of "H" plotted against "x", where "H" is the force applied horizontally to the lower clamp of the Instron Tensile Tester and "x" is the horizontal distance moved by the lower clamp. In 1969 Hearle determined that shear rigidity is equal to the weight of the load on the shear tester raised to a certain amount to produce an increased potential energy subtracted from the point of application of force displaced through a distance parallel to the force.

Another approach to evaluating fabric drape is to correlate drape measurements with properties generally associated with fabric hand (Collier et al., 1989). The Kawabata

Evaluation System consists of four instruments that provide objective measures for bending, shear, tensile, and surface and compressional properties in order to predict the hand of fabric (Kawabata, 1980). The compilation of data from the four instruments represents a total hand value. A total appearance value developed by Kawabata and Niwa (1989, cited in Kawabata & Niwa, 1991) relates to the total hand value to provide a correlation between objective and subjective measures for fabric hand. A drape component is one of three primary values used to calculate the total appearance value. These values are used to quantify the hand or drape of a fabric and to determine its suitability for tailoring and for automation of handling in the production process.

Fabric Geometry

Joseph (1986) defines fabric geometry as the relationship, or interrelationships, of fibers and yarns to their ultimate arrangement and shape in fabric. How these components are assembled influences the properties of the textile fabric, especially the arrangement of fibers into yarns and fabrics. The geometric factors in the development of a subjective description for fabric drape include fiber contour, cross-sectional shape and length, arrangement of the fibers into yarns, and the arrangement of yarns into fabric. Fabric geometry must be considered when calculating the resistance of cloth to any mechanical deformation in terms of resistance to deformation of the individual fibers (Grosberg, 1969). Fabrics made from the same fibers can differ in five respects including yarn composition, yarn count, ratio of warp count to weft count, yarn spacing, and fabrication method. The many variables of fabric geometry create the special problems in obtaining objective measurements of fabric drape. Drape measurement of fabric is dependent on how the fabric geometry interacts to produce folds.

Bending Properties

The resistance a fabric exhibits to bending is called bending stiffness or flexural rigidity. Grosberg (1966) found this stiffness or rigidity is the frictional restraint to bending that develops from the frictional rubbing between fibers in a fabric. In research to develop a computer model for predicting fabric-deformation behavior, Brown, Buchannan, and Clapp (1990) used flexural rigidity to accurately predict fabric deformation for fabric samples less than 10 centimeters long. After measuring 101 apparel fabrics using the drapemeter, Dowlen (1976) found a high correlation between the drape coefficient and warp, filling, and overall flexural rigidity of the samples. Flexural rigidity or bending stiffness takes into account both the fabric's bending length and its weight. Drape is highly correlated with bending length which is influenced by fabric weight (Brown et al., 1990; Dowlen, 1976; Gaucher et al., 1983; Ghosh et al., 1990a, 1990b, 1990c; Hearle, 1969; Lindberg et al., 1960; Smuts, Hunter, & Lombaard, 1984). Bending length is a measure of the interaction between fabric weight and fabric stiffness as demonstrated by the way in which a fabric bends under its own weight. The stiffness of a fabric when bent in one plane under the force of gravity reflects its bending length which is one component of drape (ASTM, 1990). Bending length is termed drape stiffness in Federal Specifications CCC-T-19lb, Textile Test Methods No. 5206.2 (ASTM, 1990).

Bending stiffness or flexural rigidity can be measured objectively by three methods. ASTM D 1388 (1990) incorporates the cantilever and the heart loop test procedures. ASTM D 4032 (1990) describes the circular bend test method. In the first two methods flexural rigidity is measured as the couple that is produced on either end of a fabric strip of unit width bent into unit curvature in the absence of any external loads on the fabric (ASTM, 1990). A couple is two forces having the same magnitude, parallel lines of action, and opposite directions of action. This couple, or force times distance resultant loading, causes bending (Beer, & Johnston, Jr., 1962). The cantilever method yields a direct bending length measurement. A recent study by Postle and Postle (1993) related fabric bending length to how a fabric bends under its own weight as it does during drape testing. The heart loop method requires a conversion table to determine the bending length from measurements taken during testing. Then flexural rigidity is calculated from bending length values to get an objective value which correlates with drape coefficients (ASTM, 1990). The circular bend method gives a bending stiffness value indicative of multidirectional fabric bending resistance (ASTM, 1990).

Shear Properties

Shear is the result of any load or force that acts on a fabric to change the 90 degree angle between the warp and weft yarns. The shear rigidity of fabric is its resistance to any angle change between its warp and weft yarns. Research has found that fabric must undergo shear deformation if the curvature is in more than one plane as is the case in complex draping patterns that require the fabric to bend in multiple planes (Hearle, 1969).

Drapeability of apparel fabrics depends on both bending rigidity and shear rigidity (Cusick, 1965; Ghosh et al., 1990a, 1990b, 1990c; Lindberg et al., 1960). Shear stresses produce a displacement of one plane of atoms relative to an adjacent plane of atoms. This strain is elastic if atoms keep their original neighbors (Van Vlack, 1964). Since fabric shear involves dislocation movements, the direction in which the critical shear stress is least is the direction with the shortest displacement distance and the greatest atomic density. Shear stress is defined as force per unit area and is derived from any force acting at a tangent to a plane in a material and results in or creates the shear angle (Hearle, 1969; Van Vlack, 1964). The shear angle is defined by Lindberg et al. (1960) as the angle of distortion produced when a specified couple is applied in the plane of the fabric. As defined previously, two forces having the same magnitude, parallel lines of action, and opposite sense is a couple (Beer & Johnston, Jr., 1962).

Hearle (1969) defines fabric shear strain as the deformation that occurs in fabric by uniform extension in one direction and contraction in a perpendicular direction so that the area remains constant. Collier (1990) found that fabric must undergo some shear deformation if the curvature is in more than one planar direction, as it is in complex draping patterns that require the fabric to bend in two directions. In research involving shear testing of woven textiles, Behre (1961) and Hearle (1969) found that shear is related to extension-compression in the bias direction.

Fabric shear can be measured objectively by three methods. One method uses an attachment to the Instron Tensile Tester which records load-deformation curves (Behre, 1961, Culpin, 1979; Cusick, 1961; Hamilton & Postle, 1976; Hearle, 1969; Skelton & Freeston, 1971; Spivak, 1966; Treloar, 1965). The resistance offered by the fabric sample is measured as its shear value (Behre, 1961; Cusick, 1961). The second method uses a shear tester apparatus, such as the shear tester in the FAST system, to attempt to twist a fabric sample and alter the 90 degree angle between its warp and weft yarns with a known load. The original fabric sample is a square. The apparatus deforms the original fabric sample into a parallelogram in such a way that the original lengths of the sides stay the same while the area decreases. The third method uses the Kawabata Tensile and Shear Tester which provides a value related to the shear modulus rather than a measurement of the shear angle at which the fabric begins to deform. The instrument also measures shear hysteresis. Shear hysteresis is the difference between the fabric under low stress and recovery of the same fabric from deformation (Collier, 1991). Collier et al. (1988) found correlations between shear stiffness values and shear hysteresis measurements taken from the Kawabata Tensile and Shear Tester and fabric drape coefficients. A study by Collier in 1991 confirmed these correlations and determined that the shear hysteresis measurement is the better predictor of fabric drape.

Fabric Hand

Fabric hand (or handle) is one means of defining or assessing a textile. Fabric hand is defined in a report submitted for publication and presented to AATCC Committee RA89 (1991) as "the tactile sensations or impressions which arise when fabrics are touched, squeezed, rubbed, or otherwise handled" (AATCC Technical Manual, 1991, p. 330). In a study conducted by Howorth (1964) it was found that smoothness, stiffness, and thickness accounted for most of the differences in fabric handle. Hand involves the whole fabric as it is manipulated, as it interacts with body contours and air space, or as it assumes its own three-dimensional form. Drape is included by ASTM as one component of fabric hand; and drape testing is one method used to determine fabric hand (Behery, 1986; Kim, no date).

Assessment of Fabric Hand

Fabric hand is one means of subjectively defining or assessing a textile. Subjective assessment is based on a human's ability to analyze personal experiences or perceptions relating to sensory interpretations. Consumers and designers attempt to subjectively assess fabric by folding, bending, and handling the fabric in order to understand and express their impression of hand and draping characteristics.

Consumer preference surveys have been conducted by many researchers (Jacobsen, Fritz, Dhingra & Postle, 1992; Laughlin, 1991a, 1991b; Winakor, Kim & Wolins, 1980). Fabric hand can be objectively evaluated by an expert panel or by a consumer panel. Results from the two types of panels usually do not correlate. Each group approaches the task with different desires and preconceptions for a fabric's end use. Expert panels are usually employed by manufacturers for determining the best fabric for producing a particular end use. Consumer panels have very little knowledge of textile properties, so they choose fabrics they prefer next to their skin. Since fabric prints and color also cause preference reactions from panels, hand evaluation is more objectively conducted with a blinding screen blocking the view of the fabric being tested. Some hand evaluations are conducted with a passive approach. During passive hand evaluations, the panel is allowed to only touch the fabric while it remains flat. In some studies fabrics are attached to cardboard to facilitate the passive evaluation. An active approach to hand evaluation is generally the preferred method. In active evaluations the panel picks up the fabric and manipulates it in their hands. Judgements for hand evaluations are recorded in a variety of ways. Some studies have judges record every adjective that seems to describe a fabric. Other studies have judges indicate a response on a number line between bipolar adjectives.

In a study conducted by Howorth (1964) it was found that smoothness, stiffness, and thickness accounted for the most of the differences in fabric handle. Fabric stiffness was evaluated by the Shirley Stiffness Tester. Thickness was measured by a Mercer Thickness gauge. Objective measurements of stiffness, thickness, and weight rendered values for determining the stiffness and thickness of tested fabrics. This study was unable to objectively measure fabric smoothness (Howorth, 1964). Behery (1986) found that a selection of physical tests routinely conducted with textiles related to fabric hand. Physical tests considered relevant to fabric hand include cantilever bending length, flexural rigidity, compressibility, cyclic bending, coercive couple, elastic flexural rigidity, initial tensile, and percent drape coefficient (Behery, 1986). Behery (1986) compared results from these physical tests to results obtained with the KES-FB and found significant correlation.

The current trend of testing textile low-stress mechanical properties was found to be a significant departure from traditional high-stress measurements such as breaking strength and breaking elongation. The rationale for low-stress mechanical measurements of fabrics relates to consumers no longer purchasing apparel for extended wear but for comfort in performance (Pan, Zeronian & Ryu, 1993). The quality, tailorability, and performance characteristics of fabrics have been related to their low-stress mechanical, surface, and dimension-less properties (Harwood, Weedall & Carr, 1990). Low-stress testing of fabric properties such as tensile, shear, bending, lateral compression, in-plane compression or buckling, surface friction or roughness, hygral expansion, and relaxation shrinkage produce values that have been related to fabric hand (Behery, 1986; Chen, Barker, Smith & Scruggs, 1992; Kim, Wang, Cowan & Barker, 1992; Kothari, 1985; Mahar & Postle, 1985; Stearn, D'Arcy, Postle & Mahar, 1988a, 1988b, 1988c). Experimental errors in low-stress fabric testing range from 5% to 12%, which is less than the errors found in subjective hand assessment methods (Pan et al., 1993). Methods of low-stress measurement demand greater attention to detail, precision, and accuracy and greater care in fabric handling and specimen mounting. Low-stress measurements have been successfully obtained from the KES-FB, FAST, and Instron tensile tester with appropriate attachments (Curiskis & Taylor, 1990; Pan et al., 1993; Stylios, 1991).

KES-FB. Researchers have sought to devise objective methods for obtaining measurements that correlate with subjective hand measurements. Kawabata (1980) developed a system for objectively measuring fabric hand. The Kawabata Evaluation System-Fabric Battery (KES-FB) has been strongly correlated with evaluations made by a panel of Japanese experts in assessing hand. Due to language translation problems and variations in cultural apparel desires, the KES-FB has less correlation with expert evaluations in countries other than Japan (Kothari, 1985; Mahar & Postle, 1985; Mahar, Wheelwright, Dhingra, & Postle, 1990). Lower correlations in the USA are attributed to lack of industrial use of trained experts to assess hand, the general practice of using consumer panels to gain sales knowledge as opposed to tailoring knowledge, and cultural differences in apparel preferences. Despite lower correlations within the USA, KES-FB serves as a "user friendly" means for gaining objective information of fabric properties. The low-stress measurements are placed in formulas which give primary hand values, total hand values, and data charts. Fabric sewability and best end use can be predicted from data charts produced by a computer program. Data charts suggest an acceptable range of end products for a fabric which exhibits a particular set of measurements (Kawabata & Niwa, 1989; Morooka & Niwa, 1978).

The KES-FB was originally composed of four textile testers and software, converter, and interface for a personal computer or Graphtec pen recorder. An air permeability tester (KES-F8-API) and thermal tester (KES-F7, Thermo Labo II) have been added to the system. The original four textile testers produce values that can be used in formulas to produce a total hand and primary hand evaluation for a textile. The KES-FB-1 is a textile tensile and shear tester. The KES-FB-2 is a textile pure bending tester. The KES-FB-3 is a textile compression tester. The KES-FB-4 is a textile surface friction and roughness tester.

KES-FB-1 measures low stress tensile strength by holding a fabric specimen in a horizontal position. Another clamp holds the opposing specimen edge and pulls the specimen a specified distance with a specified load. Results obtained include linearity of load-extension curve, extensibility, tensile energy, and tensile resilience. The same instrument measures low stress fabric shear. The fabric specimen is placed between both clamps. The clamps travel in opposite directions parallel to the clamped edges to shear the specimen five degrees at a known load. A transducer detects the shear resistance. Results obtained include shear stiffness and hysteresis of shear force at both 0.5 and 5 degrees shear angle.

The KES-FB-2 is a pure bending tester. Fabric specimens are held at opposite ends and moved by a crank mechanism. The bending deformation is then detected. Bending rigidity and hysteresis of the bending moment are results obtained with this instrument. The KES-FB-1 and the KES-FB-2 were used by Collier (1991) to find positive correlations with drape coefficients obtained from the same fabric specimens. The KES-FB-3 measures fabric compression. A transducer detects the fabric deformation during compression. Compressional force is specified to be an estimate of finger pressure during expert subjective hand evaluations. Results obtained include linearity of compression, compressional energy, and compressional resilience.

The KES-FB-4 is a surface friction and roughness tester. The fabric specimen is moved horizontally by rotating on a drum on which one end of the specimen is anchored. The opposite end of the specimen is held in tension. A detector records up and down displacements caused by a fabric's surface friction. A coefficient of friction and geometrical roughness are results obtained with this instrument.

FAST. The Commonwealth Scientific and Industrial Research Organization (CSIRO) developed the Fabric Assurance by Simple Testing (FAST) system in order to simulate real wear and sewing conditions in the laboratory. Textile physical properties measured by the FAST system include fabric thickness and relaxed thickness; fabric surface thickness; and relaxed surface thickness; bending length; warp, weft, and bias extensibility; relaxation shrinkage; hygral expansion; bending rigidity; shear rigidity; formability; and finish stability (Allen, Shaw, de Boos & Ly, 1990). The FAST system consists of three instruments and a test method. In general, measurements from the FAST system correlate well with corresponding measurements from the KES-FB system (Wiener, Barndt & Furniss, 1993; Ly, Tester, Buckenham, Roczniok, Adriaansen, Scaysbrook & De Jong, 1991).

The compression meter (FAST-1) measures fabric thickness at two different loads, 2 gf/cm2 and 100 gf/cm2, so that a surface layer thickness can be defined. Surface layer thickness is the difference between the two fabric measurements. Finish stability can be obtained from measurements obtained with this instrument. The difference in fabric thickness measurements when taken relaxed in steam or water and surface layer thickness is compared and expressed as a percentage (Allen et al., 1990). A correlation coefficient better than 0.99 resulted from a comparison study conducted with FAST-1 and the Shirley thickness gauge (Ly et al., 1991).

The bending meter (FAST-2) was found to have a 0.98 correlation coefficient with the KES-FB bending tester (Ly et al., 1991). This automated bending length tester is similar to the FRL cantilever, but it eliminates error due to operator judgement. The edge of the bending fabric specimen is detected by photocell instead of the human eye; and bending length measurement is instantly displayed. Flexural rigidity is calculated from bending length measurements (Allen et al., 1990). The FAST-2 does not give a separate reading for the frictional component as does the KES-FB bending tester (Ly et al., 1991).

The extensibility meter (FAST-3) measures fabric extension at three predetermined tensile loads and shear rigidity from bias extensibility. FAST-3 can measure fabric extension over a range of loads with direct readings of fabric extension as a percentage of the initial gauge length. Shear rigidity is calculated from bias extension, and formability is calculated from extensions at both 5 and 20 gm/cm together with bending rigidity (Allen et al., 1990; Ly et al., 1991). When Ly et al. (1991) compared the FAST-3 to the KES-FB tensile and shear tester, a correlation coefficient of 0.98 was found for extension and 0.94 was found for shear rigidity.

FAST-4 is a quick measure of dimensional stability. The dimensional stability test determines relaxation shrinkage and hygral expansion without the need for a controlled environment laboratory. Time for conducting the test is reduced to one hour. A fabric specimen is dried to zero regain to measure its dry dimensions. Then the specimen is soaked in water to measure its wet relaxed dimensions. The specimen is then dried in a conventional or microwave (preferred) oven in order to measure final dry dimensions. The relaxation shrinkage and hygral expansion are calculated, and a schematic representation is plotted (Ly et al., 1991). This test method for dimensional stability correlates well with measures from the conventional wet-dry test for wool-rich fabrics (Curiskis & Taylor, 1990).

Instron Tensile Testers. All fabric properties that are tested with KES-FB can also be evaluated on the Instron tensile tester with proper attachments. Since the Instron was designed for tensile testing, there is no problem in preforming the test other than adjusting the traditional settings to settings providing lower load and extension stress to fabrics. Instron tensile testers can be adapted with appropriate jigs to measure low stress compression, thickness, bending, shear, and friction properties. Fabric in-plane compression/buckling, in both the principal and bias directions, can be examined by means of plane clamps attached to the Instron (Curiskis & Taylor, 1990). A compression cell can be used for measuring fabric compression, thickness, and bending. To measure fabric bending Pan et al. (1993) seamed together two sides of a rectangular shaped fabric specimen to form a tube. The fabric tube was compressed to a given displacement (Pan et al., 1993). Chen et al. (1992) developed a low stress pure bending test that highly correlated with results obtained from the KES-FB pure bending tester. A loop of fabric is clamped by loose ends in the Instron tensile tester crosshead. A compression sensor is placed beneath the loop. Measurement readings are obtained as the fabric loop is lowered to contact the sensor. This research group is in process of developing methods for using conventional textile testing equipment, especially the Instron tensile tester, to obtain compatible data with KES-FB shear and friction tests (Chen et al., 1992). Pan et al (1993) used a bias tensile test for measuring fabric shear. Previous studies have rejected using the Instron tensile tester without an attachment for measuring fabric shear (Behre, 1961; Cusick, 1961; Spivak & Treloar, 1968; Treloar, 1965). Pan et al. (1993) argue that under low stress levels fabric shearing tests and bias tensile tests obtain the same measurement of fabric yarn mobility (shear). The bias tensile test relates to shear testing results obtained with the FAST system (Pan et al., 1993). Fabric friction can be measured as stated in ASTM D1984 by using an Instron attachment for this purpose. An illustration of the attachment is presented with results of a study by Ajayi (1992). Circular fabric can be drawn through a nozzle by an Instron tensile tester to obtain a measurement (slope of force-displacement) used to calculate a handle modulus. The cross-head and chart speeds are set at

50.8 cm/minute. The nozzle has a minimum radius of 5mm. Handle modulus was significantly correlated to primary hand values for summer fabrics measured by KES-FB and an expert panel (Behery, 1986). Low-stress measurements taken with the Instron tensile tester can be charted in a circular map to create a picture or thumbprint of a specific fabric's characteristics. These characteristics can be compared to similar fabrics for quality control or for planning end use (Pan et al., 1993).

Other Objective Methods for Measuring Fabric Hand. Olsen and Broome (1977) compared a subjective hand evaluations to objective measurements of changes in the pupil size due to stimulus by the same fabric specimens. Objective measurements were made possible with a pupillometric apparatus. The apparatus allowed the subject to use a standard ophthalmologist's headrest and photographic equipment. The camera was loaded with high speed infrared film and set to automatically take four frames per second with a 0.25 second exposure. An infrared filter covered the lighting source. The pupil changed in size with the change of fabric specimen texture. Pupil dilation was found to be greatest for the most comfortable fabric specimen. The pupil constricted the most for the least comfortable fabric specimen. The apparatus was also able to provide enough measurement variations for forming a comfort preference scale for fabrics tested (Olsen & Broome, 1977).

Assessment of Drape

Unlike most material used for construction, fabric is valued for its ability to bend, buckle, fold, and drape under low stress. Fabric is unique in that it maintains its construction and strength while remaining flexible and experiencing multi-dimensional deformation. The large number of degrees of freedom of movement in a textile make a definitive measure of its deformability difficult to ascertain.

Subjective

Drape testing is conducted subjectively by handling the fabric and draping fabric on the hand or human form. Another means of subjective assessment of fabric drape involves evaluations by either expert or consumer panels. Chu et al. (1960) reported a correlation of 0.788 between drape coefficients and evaluations by 57 observers (consumers of various backgrounds) when the observers were asked to rank the order of fabric drapability.

Cusick (1965) emphasized the importance of subjective research when he stated that "Drape is a subjective property, and an instrument that measures drape should produce results that correlate with subjective tests" (p. T596). In 1962 Cusick conducted three subjective tests for evaluating fabric drape. In the first test, five textile experts formed a panel for judging the drape order of eight fabrics. Half skirts were constructed of each fabric and tied on models. Judges were asked which fabric drapes the most and which drape was most preferred. Then a larger panel was shown photographs of the same eight skirts and asked the same questions. Later only six of the skirt photographs were shown to panels. A higher correlation was found for comparing fabric drape rank orders than drape preferences to drape coefficients. It was concluded that fashion trends influence drape preference (Cusick, 1962, cited in Hearle, 1969).

Sudnik incorporated subjective evaluations of 18 fabrics in his 1972 study. The fabrics were constructed into garments and curtains. People were asked to classify the fabrics for drape preference. Three categories of fabric drape preference were determined: (1) firm with symmetrical folds, (2) limp with numerous soft folds, and (3) graceful folds that move with the fabric construction (Sudnik, 1972).

In 1991, Collier asked a panel of apparel design students to subjective evaluate 17 fabrics for drape rank order and drape preference. A correlation value of 0.93 was reported for comparing subjective evaluations and drape coefficients for fabric drape rank orders (Collier, 1991).

Objective

Researchers have attempted to assess drape objectively as well as subjectively. Objective assessment controls variables in order to obtain facts without distortion of personal feelings or prejudices. Fabric drape is generally expressed objectively by the node count and the drape coefficient. Other objective measurements of fabric drape include assessing mechanical properties such as fabric flexural rigidity and shear rigidity that correlate with the drape coefficient (Cusick, 1965; Lindberg et al., 1960; Postle & Postle, 1992, 1993).

Objective assessments of drape include readings from mechanical devices called drapemeters or drape testers. A review of literature reveals that at least three different drapemeters have been developed. The FRL drapemeter is the most commonly used and will be described in a later section. Very little is known about the other drapemeters.

FRL Drapemeters

The drapemeter is based on the traditional principle used for displaying fabrics draped over circular pedestals in store windows (Chu et al., 1950; Merkel, 1991). The Research and Marketing Act of 1946 authorized the United States Department of Agriculture to contract the Fabric Research Laboratories in Boston, Massachusetts to build an apparatus for objectively measuring fabric drape (Chu, Platt, & Hamburger, 1960). The Fabric Research Laboratories

(FRL) developed an instrument which provides means for measuring an optically projected shadow image of a draped fabric specimen. This apparatus was named the FRL drapemeter.

The original instrument contained a sample holder consisting of two flat plates, circular in shape, mounted on a shaft coming through the base of the tester. A circular fabric sample was sandwiched between the plates, and the shaft was raised until the overhanging portions of the sample no longer touched the base. The image created by the fabric specimen's draping pattern was cast onto a sheet of ground glass by means of a lens and mirror system. The drapemeter lens and mirror system were similar to that of an overhead projector. The projected shadow diagram was traced on a thin piece of paper (Chu et al., 1950).

Chu et al. (1950) of the Fabric Research Laboratory modified the original FRL Drapemeter. The modified FRL Drapemeter used one of two synchronized turntables to support the drape specimen, with a standard circular chart mounted on the other turntable. A light beam was focused on a photocell which scanned the draped specimen around its edges. A pen was mechanically connected to the scanning unit to record the movements of the photocell. When the turntables completed one revolution, an accurate vertical projection was drawn on the circular chart. The fabric specimens were circles of 25 centimeter (10 inch) diameters. Specimens of 30 centimeter (12 inch) diameters could also be accommodated. All specimens required conditioning for 24 hours prior to testing. A 1/4 inch hole was cut in the center of each specimen so it could be placed on the pedestal directly with evenly draped sides.

Cusick (1965) used fabric specimens with 30 centimeter (12 inch) diameters and draped them over the 18 centimeter (7 inch) diameter disc which was used in the modified FRL drapemeter. To test the fabric circles, the specimen was placed on the lower disc and pressed down so the center-locating pin protruded through the fabric. The upper disc was placed on top, then both discs were raised to pedestal height. Cusick (1965) found that the outline of the shadow needed to be drawn immediately (15 seconds within placing the sample on the disk) to avoid distortion since fabric deformation varies with time. However, both Cusick (1968) and Dowlen (1976) later found that variation in the shadows (node formation) of the draped fabrics did not significantly affect the drape coefficients. Cusick (1965) also altered the position of the light source in an effort to reduce any error resulting from convergent or divergent projections of the specimen shadow and therefore the measurement of the shadow's area. Later the substitution of a concave mirror for the existing flat mirror eliminated the problem of the convergent and divergent shadow projections.

The present form of the FRL drapemeter uses a fresnel lens to improve the resolution of the projected fabric drape shadow. The fabric support platform is a stationary 4 inch diameter circle (with no edge curvature) approximately 5 inches above the fresnel lens. Standard measurement protocol specifies a 10 inch diameter fabric specimen.

Other Drape Testers

Cusick's modifications to the FRL drapemeter resulted in the development of the Cusick drape tester. The lid of the cusick drape tester is raised to insert a fabric specimen between two horizontal circular plates. While the lid is raised the fabric specimen is supported by a ring. During testing the lid is lowered and the ring is removed; thus, allowing the specimen to drape under its own weight. A light source and a parabolic mirror beneath the specimen create parallel light which causes a shadow of the specimen to be projected on a paper circle (the same size as the fabric specimen) placed on the tester lid. The shadow is traced. The paper circle is weighed (W1). Then the shadow is cut from the paper circle and weighed

(W2). The weight of shadow diagram area yields a variable value in the formula for determining a drape coefficient:

$$DC = \frac{W2}{W1} X\ 100$$

(Kim, 1975; Sudnik, 1972). Sudnik used the Cusick drape tester in 1972 to obtain objective drape measurements for 18 fabrics during his study of fabric draping quality. Kim also used the Cusick drape tester for his study of fabric hand in 1975.

El-Bayoumi used the P.V.O.I. Drapemeter in a 1980 study comparing the drape of laundered cotton fabrics. Specimens for drape testing were cut 28 X 28 centimeters (El-Bayoumi, 1980). Gaucher et al. (1983) conducted an objective study of fabric drape using a Rotrakote tester and the British Standard Method BS:5058-1973 Assessment of Fabric Drape. Two 30 cm diameter fabric circles were cut from 19 knit fabrics. The fabric specimens were placed over an 18 cm diameter platform disc for testing. Results were reported as drape coefficients (Gaucher et al., 1983).

Nishikawa et al. (1987) developed a non-contact method for measuring the surface shape of draped fabrics by using ultrasonic sensors. The research expanded to the development of a devise for measuring the surface shape of garment as it draped on a human manikin. The device consists of an ultrasonic sensor attached to a mechanical arm which rotates systematically around a dressed manikin. The ultrasonic sensor measures the draped fabric surface while maintaining a known distance and calculating the time needed for reflecting the ultrasonic waves. The measurements are transmitted to a central processing unit where co-ordinates of the measured position are calculated. The resultant series of co-ordinates are displayed on a computer monitor as a three-dimensional reproduction of the draped fabric surface (Nishikawa et al., 1987).

Collier et al. (1988) developed a drape tester using photovoltaic cells to detect the drape diagram. In 1991, Collier et al. improved this drape tester to use a geometric non-linear finite-element method to measure drape. The drape tester consisted of a box containing a pedestal with a flat metal plate 13 centimeters (5 inches) in diameter. A light source was placed directly over the specimen. Each DV obtained with this drape tester was used to calculate a finite-element mesh. The finite-element meshes were used for modelling the behavior of draped fabric specimens. The amount of light blocked by the fabric sample was detected by photovoltaic cells on the interior base of the box. A direct reading was obtained by a digital voltmeter. Each mesh was based on three-dimensional graphing where there is an "x-y" plane with a perpendicular "z" axis. The circular fabric sample was considered to be held initially flat in the "x-y" plane and then released. The deformed area on the "x-y" plane was projected and recorded as the drape value.

The Massachusetts Institute of Technology (MIT) drapemeter measures drape or multi-directional bending based on simple bending of rectangular fabric strips under normal gravitational force. The fabric specimen is attached to an identified circumference of a circular disc and allowed to hang. A measurement of a fabric's stiffness is obtained by measuring the length of fabric which falls below the support platform disc (Cassidy, Cassidy, Cassie, & Arkison, 1991). Use of the MIT drapemeter yields a value termed drape coefficient.

Quantification of Fabric Drape

Neither ASTM nor AATCC has developed a consensus method for measuring fabric drape. Without a consensus method, researchers must develop their own method or follow the protocol of previous researchers. Since the development of the FRL drapemeter, many researchers have quantified fabric drape with the drape coefficient (DC).

Drape Coefficient/Drape Values

While modifying the FRL drapemeter, Chu et al. (1960) concluded that drapability of a fabric depends on three basic parameters: Young's modulus (E), moment of inertia of the cross-section (I), and weight (W). A relationship between measurements of these three parameters yields a drape coefficient, where

$$DC = \frac{EI}{W}$$

Greater fabric drapability is indicated by a combination of low E and I values and a high W value. To obtain a low fabric modulus (E) a fabric must have an open weave which permits greater yarn mobility, long float lengths as in twill and satin weaves, high twist yarns, and/or applied softeners and lubricants. To obtain a low fabric cross-sectional moment of inertia a fabric must be thin. Thin fabrics can be manufactured by weaving fine yarns or by flattening yarns with a calendering process. To obtain a high fabric weight, a fabric could be manufactured with coarser yarns, a greater number of yarns, crimped yarns, or by loading the fabric with non-fibrous finishes (Chu et al., 1960).

The DC is also the resultant percent obtained from multiplying 100 by a ratio of areas measured by standard protocol with the FRL drapemeter. The standard protocol specifies a drape support platform that is 4 inches in diameter and a fabric specimen that is 10 inches in diameter. The DC equals (the area of the projected drape diagram shadow (AS) minus the area of the support platform (AP)) divided by (the area of the fabric specimen (AF) minus the area of the support platform (AP)) multiplied by 100:

$$DC = \frac{AS - AP}{AF - AP} X\ 100$$

(Chu et al, 1950; Chu et al, 1960; Cusick, 1968; Dowlen, 1976; Sudnik, 1972).

Other researchers have used variations of the standard protocol with the FRL drapemeter and similar drape testers. When the standard protocol was al.tered, confusion in fabric drape quantification terminology developed. Researchers termed the obtained percent either drape coefficient or drape val.ue (DV). Cusick (1968) and Sudnik (1972) measured fabric specimens of three diameters on the Cusick drape tester, but they termed al.l results as drape coefficients. Collier (1991) obtained fabric drape val.ues while using a drape tester that had nonstandard fabric support platforms (3 and 5 inch diameters). In this study DC was used to present results obtained by standard measurement protocol, and DV was used to distinguish quantification of fabric drape when standard measurement protocol was al.tered.

The difference between the terms fabric characteristic and fabric property is defined by Solinger (1988). Solinger (1988) describes a fabric property as a static physical. dimension. Fabric characteristic is defined as the reaction of a fabric when a force is imposed upon it; fabric characteristics are the dynamic physical. parameters of a fabric (Solinger, 1988). Most sources of textile descriptions and test methods equate definitions for textile characteristics and properties or group the two terms without distinction in one category (Joseph, 1986; Kadolph, Langford, Hollen, & Saddler, 1993; Linton, 1966; Wingate, 1976; Yeager, 1988). ASTM D 123 (1992) defines a fabric characteristic as "a property of items in a sample or population which, when measured, counted, or likewise observed, helps to distinguish between the items" (p. 17). AATCC has not addressed these terms in the 1992 glossary of standard terminology. For this study fabric drape is considered to be a fabric characteristic affected by many variables. The DC cannot be considered a fabric property even when measured under standard FRL drapemeter protocol since it is difficult to ascertain the inherent property of fabric drape. Al.so, since the DV is dependent on variations in standard FRL drapemeter protocol, the DV is not considered a fabric property in this study.

Area Measurements

Another objective measure of fabric drape involves a drapemeter and produces a val.ue which is sometimes reported as the drape coefficient. The drape coefficient of fabric can be cal.culated from drape diagrams obtained from the drapemeter or similar drape tester. A 4 inch diameter pedestal., which can be made by hand and used with a spotlight can serve for drape testing. One or two 10 inch cardboard disks and paper are needed to record the drape coefficient by this method (Merkel, 1991). One method of cal.culating drape coefficient readings involves tracing the drape shadow diagrams on paper and then cutting out and weighing these traced diagrams. This method is based on the principle that the actual. area of a material. is directly proportional. to the weight of the shadowed area of that same material.. Circles which represent the circumferences of the draping platform and the fabric sample are cut from the same paper and weighed. The weight of the shadow diagram is compared to the weights of the circles to cal.culate drape coefficient (Cusick, 1968; Dowlen, 1976). (The weight of the paper circle representing the draping platform is subtracted from the weight of the shadow diagram. The resultant weight is the numerator of the drape ratio. The weight of the paper circle representing the draping platform is then subtracted from the weight of the paper circle representing the fabric sample and this resultant becomes the denominator of the proportion.)

A planimeter can be used to obtain area measurements as the shadow of the fabric drape diagram is traced. The area measurements of the fabric support platform, the fabric specimen, and the drape diagram are substituted for corresponding weight measurements to obtain the drape coefficient. Cusick used a planimeter to measure the area of drape diagrams by tracing the outline of projected shadows in his 1968 study.

Use of an optical. scanner or a digital. computer to cal.culate the area of drape shadow diagrams is a more sophisticated technique for determining the drape coefficient. These methods display the drape coefficient as a difference between the area of the drape shadow diagram and the area of the fabric sample.

Node Count

A measure of drape can be accomplished by counting the nodes of the shadow diagram projected by the drapemeter. Nodes are outward double curves of fabric and are recorded from the traced shadow diagram. The number of nodes in a shadow diagram is one indication of the stiffness or flexibility of a fabric. Studies of shadow diagrams have reveal.ed that the number of nodes is inversely related to the drape coefficient. A smal.l number of shadow diagram nodes corresponds to a large drape coefficient and a stiff fabric, and a large number of nodes corresponds to a smal.l drape coefficient and a flexible fabric (Collier, 1990; Dowlen, 1976; Hearle, 1969). Since the number of nodes formed during draping changes with repeated tests (repeatability equal.s less than 75%) of the same fabric specimen, node counts have been found to be less precise in predicting fabric drape than drape coefficients (Hearle, 1969). Dowlen (1976) found that drape diagrams often change by one to two nodes when a specimen is retested. She al.so found that changes in a specimen's node count has no influence on its drape coefficient (Dowlen, 1976).

Drape Testing Variation

Since fabric drape is important to the apparel industry, there have been numerous studies with a variety of approaches. Researchers seek methodology for quantifying fabric drape and relating the draped fabric behavior to garments. Because fabric drape is as difficult to assess as it is to define, researchers have developed a variety of means for objectively obtaining numerical results (Amirayat & Hearle, 1989; Chu et al., 1950; Chu et al., 1960; Collier, 1990, 1991; Collier et al., 1989; Collier et al., 1991; Cusick, 1968; Dhande et al., 1993; Dowlen, 1976; El-Bayoumi, 1980; Gaucher et al., 1983; Hearle, 1969; Moore, 1992; Moore et al., 1990; Moore, Gurel & Lentner, in press; Nishikawa et al., 1987; Postle & Postle, 1993; Sudnick, 1972).

Fabric Overhang Lengths

In 1968 Cusick studied drape overhang length in relationship to drape testing accuracy. The platform for his drape tester was a circle 18 centimeters (7 inches) in diameter. Fabric specimens were cut in circles with diameters of 24 centimeters (10 inches), 30 centimeters (12 inches), and 36 centimeters (14 inches). The traditional specimen diameter of that time was 30 centimeters. Cusick (1968) found that very stiff fabrics could be measured more consistently when using the largest fabric specimen (longest overhang); fabrics of medium drape coefficients could be measured more consistently when using the 24 centimeter diameter specimen size; and very limp fabrics could be measured more consistently when using this smaller fabric specimen (shortest overhang).

In 1972 Sudnik repeated Cusick's (1968) study of drape overhang length with 18 fabrics. Sudnik (1972) used the same platform and specimen dimensions as Cusick (1968). Fabrics were divided into groups identified by high (85%), medium (60%), and low (30%) drape coefficients. All fabrics were cut to all specimen sizes and measured for drape. The two larger specimen sizes (longer overhang lengths) were found to consistently measure al.l levels of drape coefficients. The smal.lest specimen size only measured the medium and low groups consistently. Spearman's rank correlations indicated more drape testing reliability for the largest specimen size. Sudnik (1972) recommended for future drape studies to use specimens of either 30 or 36 centimeter (12 or 14 inch) diameters.

Hearle and Amirbayat (1986) studied the relationship between fabric density and specimen overhang length during drape testing. Fabrics were cut into four sets of eighteen specimens. For testing the effect of fabric overhang length, specimen diameters ranged from 22 cm to 36 cm and varied by 1 cm increments. To test the effect of fabric weight, four fabrics were cut in specimens of three different diameters (24 cm, 30 cm, and 15 cm). Four tests were conducted with each specimen. The first test was conducted with plain fabrics. The second test was conducted with fabric that was loaded by adding one pin (0.106 g) per 4 cm^2. The third and fourth tests were conducted by loading the specimens with one pin per 2 cm^2 and one pin per 1 cm^2, respectively. Results indicated decreased DC for heavier fabrics due to gravitational potential energy increasing relative to the fabric's bending energy (Hearle & Amirbayat, 1986).

In 1988 Collier, Collier, Scarberry, and Swearingen developed a drape tester with two platforms. Both platforms were circular but differed in diameter. Fabric specimens were cut in 10 inch diameter specimens that were draped over the 3 inch and 5 inch diameter platforms respectively. Differences in drape values due to changes in drape overhang length were found. The drape values obtained when the specimens were draped over the 3 inch diameter platform correlated more highly with the fabric's shear properties. In 1991 Collier repeated the study with fabric drape overhang length and found that drape values were higher when the 3 inch platform was used. The coefficient of variation was also lower for drape testing with the 3 inch diameter platform. Thus, Collier's (1991) study indicated higher precision for drape testing when drape overhang length was increased.

Area Diagrams

In 1976 Dowlen assigned categories to basic drape diagram shapes. Categories sorted diagrams into slightly distorted circles, ellipses, triangles, rectangles, and shapes that represent the number, placement, and length of diagram nodes.

Sudnick (1972) asked a group of non-expert observers to determine good drape for 18 fabrics made into both garments and curtains. Drape preferences were grouped into three categories. The first category indicated that consumers prefer stiff fabrics (indicated by large drape coefficients) with few but regular wide and shallow symmetrical folds (indicated by nodes on drape diagrams). The second category related to a consumer preference for limp fabrics (indicated by small drape coefficients) with numerous, small, evenly spaced, symmetrical folds. The third category was established for those consumers that preferred graceful, fluid fabrics that move with the supporting body. Fabrics grouped in the third category were distinguished during objective drape testing by regular, long symmetrical folds. In summation, all observers preferred fabrics that naturally drape with evenly spaced, symmetrical folds (Sudnik, 1972).

Implications of Drape Assessment

The apparel manufacturing industry will benefit from the successful development of computer graphic simulation of patternmaking by the fabric draping method. Time (improved quick response), flexibility, and cost reduction in the design department will allow creative personnel to generate more designs with more fabric possibilities and better fit without actually purchasing fabric for draping or prototype samples. Costs to construct prototypes can be drastically reduced or eliminated. A successful design can be simulated in a different fabric weight and/or texture for a different season without having to make trial samples from proposed fabrics (Collier, 1990; Shishoo, 1990a, 1990b).

Another advantage of developing a computer graphic simulation program for patternmaking by the fabric draping method is the potential integration of all apparel design steps with other apparel manufacturing phases. Many other apparel design and patternmaking processes are already computerized. The designer can create a fashion sketch, change the print coloration of a given fabric, scan or digitize flat pattern pieces, create flat patterns from basic geometric shapes or sloper libraries, grade flat pattern pieces for a variety of sizes, plan and plot pattern markers, and efficiently cut fabrics using computer technology. Since there are garment designs which are best created from patterns produced by the fabric draping method, a computer program which can simulate this process would close a gap in computer integrated manufacturing. In order to develop a computer program for graphic simulation of patternmaking by the fabric drape method, a computer program for graphic simulation of fabric drape must be developed (Collier, 1990; Harlock, 1989; Jacobs-Blecha & Riall, 1990; Kosh, 1990; Lee & Steer, 1991; Shishoo, 1990a).

Computer Graphic Simulation of Fabric Drape

Researchers have related fabric properties to fabric drape values (Collier et al., 1989; Cusick, 1965; Lindberg et al., 1960; Postle & Postle, 1992, 1993). Since many fabric properties are assessed before a fabric becomes a tool for apparel designers, a data bank of these fabric properties can be created and this data bank can serve as a base for variables in calculations which predict fabric drape (Deschamps & Ceith, 1985; Harlock, 1989). In 1990 Collier emphasized a need for further research in predicting the deformation of fabrics during draping because the shapes formed by different fabrics due to support surfaces and gravitational forces could be assessed during the initial design phase. Dhande et al. (1993) have used the concepts of intrinsic geometry parameters to develop computerized geometric models of draped fabric surfaces based on fabric bending properties. They have also explored the geometries of a variety of fabric support surfaces. The geometric models have been generated to render several surfaces similar to the apparel support surfaces on the human body with the intent of using the method as a predictive tool for apparel designers (Dhande et al, 1993).

Other Approaches to Computer Graphic Simulation of Fabric Drape

A review of literature on computer graphic simulation of fabric drape and its potential impact on the designing of apparel within the garment manufacturing industry reveals a variety of approaches. Several three-dimensional (3D) computer aided design (CAD) systems currently produce enhanced two-dimensional (2D), photograph quality fashion illustrations using contour mapping techniques (Freedman, 1990; Harlock, 1989; Waddell, 1992). Harlock (1989) found one softwear producer which has developed a 3D patternmaking program. The program produces a fashion illustration which allows fabric designs to be mapped on a rotating mesh human body. The 3D illustration can be flattened to create 2D pattern pieces. The 2D pattern pieces can be plotted and seamed together to create the illustrated garment. A data bank of fabric physical properties is incorporated into mathematical models which predict the drape of the illustrated fabric. The mathematical models are complex; thus, the program is not currently accepted as a commercial apparel designer tool (Harlock, 1990).

Other program developers use finite element techniques common to CAD systems employed by mechanical and civil engineers. Finite element techniques are suitable for predicting small deformations of materials subjected to a known load; but these techniques are not always applicable to textile materials which normally exhibit large deformations under relatively low forces (Harlock, 1989).

Several studies have produced mathematical models for mapping textile materials on spherical surfaces (Basset & Postle, 1990; Heisey & Haller, 1988; Hogfors & Edberg, 1990; Van West, Pipes & Keefe, 1990). In 1988 Heisey and Haller developed a model for calculating the drape of a woven fabric on a 3D surface. Each yarn composing the fabric was traced along a 3D surface. The traced yarns and their sheared intersections created a mapping technique. By tracing each fabric yarn as it contours to a surface, the mathematical model is able to simulate an apparel designer placing woven fabric grainlines while patternmaking by the fabric draping method. Pattern seam needs are indicated by results which represent fabric buckling. The Heisey and Haller (1988) program is limited by requirements for the textile to be in continuous contact with its support surface which is an unrealistic assumption for garments constructed from woven fabrics. In 1990 Van West, Pipes, and Keefe developed a computer graphic simulation for draping woven fabrics over a variety of surfaces. The computer graphic simulation is based on a mathematical model which calculates bidirectional fabrics over support surfaces. Each yarn of the fabric was traced to determine yarn intersections. Yarn intersections are used to map the relationship between the support surface and the draped fabric. The yarn intersections are defined numerically by co-ordinates of intersection points. Since this program incorporates a means for determining the presence and location of fabric wrinkling and fabric bridging, garment ease needs can be mapped; thus, the Van West, Pipes, and Keefe (1990) program has the potential of producing realistic fabric and garment drape.

Development of Drape Testing Equipment

In order to continue research with geometric modeling of draped fabric surfaces Dhande et al. (1993) have expressed a need to compare photographs obtained from drapemeter experiments with fabrics draped on a variety of surfaces representative of the human body to their computer graphic simulations. Dhande et al. (1993) also needed to compare resultant computer graphic simulations with photographs obtained from drape tested fabric samples with overhang lengths greater than those of standard drape testing protocol. Before constructing a drape testing apparatus that could provide comparison objective measurements and needed photographs for continuing the research of Dhande et al. (1993), it was necessary to review literature on fabric test method development and light theory factors influencing the development of a modified drapemeter.

Fabric Test Method Development

Major sources for standard test methods for textiles include ASTM; AATCC; Federal Standard Textile Test Methods, Standard No. 191; American National Standards Institute (ANSI), and International Standards Organization (ISO). Many of the Federal Standard textile test methods and ANSI test methods are adopted from ASTM and AATCC test methods. Both ASTM and AATCC have guidelines for developing consensus test methods.

Precision and accuracy statements are a part of many of the ASTM and AATCC test methods. Precision is the degree of agreement within a set of observations or test results obtained by using a test method. In other words, precision is the repeatability of test results for single-operator or multi-operator within the same laboratory on different dates or between laboratories. Accuracy is the degree of agreement between the true value of the property being tested and the average of many observations made according to the test method.

Cary and Sproles (1978) developed a framework for guiding test method development policy-makers. Since there is no published standard test method for measuring fabric drape, the traditional protocol for measuring fabric drape with the FRL drapemeter was evaluated by the Cary and Sproles (1978) guide. The Cary and Sproles (1978) test method framework is composed of three levels. The first level relates to the utility of a test method. The second level describes the concepts of the validity, reliability, manageability, and essentiality of a test method. The third level comprises objective and subjective means for evaluating level two components (Cary & Sproles, 1978).

Cary and Sproles (1978) define utility as an aggregate measure of its theoretical and practical applicability for measuring a defined property of a product. If each of the level two components are acceptable, then the test method can be considered useful. Utility is established if there is scientific merit for measuring a particular property, if the method for measurement of the particular property is simple and parsimonious, and if the measurement results are meaningful and relevant to those who are affected by their use.

Validity is defined by Cary and Sproles (1978) as the accuracy of a test method or a true representation of the property it is designed to measure. (ASTM prefers to use the term "lack of bias" instead of validity.) Level three factors for validity are face validity, sensitivity, and predictivity.

Reliability is defined in the framework as the precision of the test method or its tendency to provide consistent results for identical objects. (ASTM prefers to use the terminology "precision" as opposed to its synonym reliability.) Level three factors for reliability include face reliability, single-operator-within-time reliability, single-operator-between-times reliability, within-laboratory reliability, and between-laboratory reliability (Cary & Sproles, 1978). The present study only included the first four factors of reliability.

Manageability of a test method is defined as the amount of resources which must be organized and controlled in order to use the method. Level three factors for manageability are face manageability, dependability, cost, and simplicity (Cary & Sproles, 1978).

Essentiality is defined in the framework as the need for and the significance of a test method. Level three factors for determining essentiality are face essentiality, interpretability, versatility, and priority (Cary & Sproles, 1978).

This test method framework was used in 1979 by Cary and Sproles, in 1981 by Cary, in 1983 by Hellmann-Tuitert and Kanis, and in 1992 by Horswill, Young, Gordon, and Sarmadi. In 1986, an ASTM task group led by Richard Cary used the framework for developing Test Method D 4772. The task group replaced two framework level two factors with synonyms in order to be consistent with established ASTM terminology. The validity factor was changed to lack of bias, and the reliability factor was changed to precision.

Light Theory Factors Influencing Modified Drapemeter Development

The focal length of the chosen fresnel lens had an impact on the construction of a modified drapemeter. In order to develop a drapemeter with directed light that would create a definite drape shadow diagram, a review of how light is affected by lenses was necessary.

Optics

Optics is a branch of physics that studies light and its properties. Physical optics describes the phenomena of light and explains its mechanisms. This branch of optics is concerned with theories of waves and electromagnetism as they apply to light. Basic principles used in the study of light are embodied in electromagnetic theory as conceived by James Clark Maxwell and transverse wave motion theory as proposed by Christian Huygens. Geometrical optics deals with reflection and refraction of light waves. The geometrical branch of optics involves using mirrors, lenses, and prisms to study light and to control the deviations of light rays. Light rays deviate when they experience a change of medium or encounter an obstacle (Besancon, 1966; Born & Wolf, 1965).

Measurement of Light

The standard measurement for light is based upon the flame of a standard candle which is 1 inch in diameter. A measure of one foot-candle of light is the intensity of illumination measured horizontally at a distance of one foot from the candle flame. One candle power of light is the illumination produced by the flame of one standard candle. The amount of light a source casts on the surface of an adjacent object varies inversely with the square distance from that source (inverse square law) and also depends on the candle power of the source. If a horizontal surface is illuminated by a source of 100 candle power 10 feet straight away, the intensity of light on this surface is found by dividing 100 by the square of the distance, which is 10 times 10, or 100. Thus, the measure of light on the horizontal surface is one foot-candle. If the source were increased to 1000 candle power, the intensity of the light on the horizontal surface 10 feet from the source would be 10 foot-candles. If the distance of the light source from the horizontal surface is doubled, the intensity of the light on the surface is reduced to one quarter of its former measurement. Likewise, if the distance between the light and the source is reduced to 1/3 of its original amount, the intensity of light cast on the horizontal surface is increased 9 times (Hewitt, 1989).

If a hollow sphere with a radius of one foot contains a light source at its center that has an intensity of light measured at one candle power in all directions, the rate at which the light would fall upon a square foot of the inside surface of the sphere is called a lumen. Since there are 4 pi square feet on the inner surface of the sphere, the source of one candle power gives off light in all directions at the rate of 4 pi or 12.57 lumens. Therefore, light falling on the inner sphere surface at the rate of one lumen per square foot produces one foot-candle of illumination on that surface. The lumen is used to rate the output of light sources, and output efficiency is determined by the watts necessary to produce a lumen. Output efficiency is expressed in lumens per watt (Stevens, 1969).

How Light Travels

If one end of a rope is fastened to a wall and the other end is shaken, the results are similar to the behavior of light. The rope demonstrates that the vibrations are perpendicular to the length of the rope. The waves travel along the rope but the rope itself moves up and down. Waves which behave in this manner are called transverse waves. Waves of light move in one direction, but each wave usually vibrates at right angles in all directions to the path the wave is travelling. Therefore, one ray of light is made up of many waves that vibrate in different directions, but always perpendicular to the direction of the ray. Sunlight and all other normal light rays are made up of such waves (Hewitt, 1989).

An object is said to be transparent if it is possible for light to pass unimpeded through it. A clear glass pane is transparent. If an object such as frosted glass scatters light that passes through it, the object is defined as being translucent. An opaque object does not allow any light to pass through it. A mirror or polished surface reflects light with little or no distortion and therefore without scattering the light. Such a reflection is called regular or specular. Light is reflected from a mirror or polished surface at the same angle at which it arrived. These equal angles of arrival and departure are referred to as the angle of incidence and the angle of reflection, respectively. The angle of incidence is always equal to the angle of reflection. When an object reflects light in all directions the reflected light rays are said to be diffused. An example of a material which does diffuse light is white blotting paper. Spread reflection occurs when an object reflects light in neither a fully regular or fully diffused pattern. Light striking a sand-blasted glass or metal surface produces a spread reflection (Callister, 1991; Hewitt, 1989; Meyer-Arendt, 1972).

When light strikes the surface of a transparent material perpendicularly, it normally travels through the substance in a straight line. But light bends when it passes into a transparent substance at an angle. For example, a ray of light travelling through air will bend when it enters a glass of water at an angle. This bending of light is due to the fact that light travels at slightly different speeds in different substances. The portion of a light wave that initially strikes the surface of a refractive substance is subjected to a greater resistance and therefore a decreased velocity or speed. Consequently, the light beam is bent toward a line perpendicular to the surface. But if the ray of light passes through a substance in which the light can move more swiftly, the ray of light is bent away from the perpendicular (Beiser, 1973; Born & Wolf, 1965; Hewitt, 1989).

Reflection of Light Waves. Light, heat, sound, and radio exits as waves of energy. When such a wave strikes a surface, it is returned or reflected. The bouncing of a ball when dropped on the floor is similar to reflection. A ball dropped at a right angle to the floor will rebound in the same line. If a ball is thrown along a path which is less than ninety degrees with the floor, the angle of its rebound or reflection will be the same as its angle of approach or incidence but in the opposite direction. These two angles are always equal (Beiser, 1973; Hewitt, 1989).

Refraction of Light Waves. Refraction is the bending or change in direction of light that occurs when light waves pass from one transparent material of a certain density into a second transparent material of a differing density. The change in resistance due to the different densities of materials results in the bending or refracting of the light waves. A pencil standing in a glass of water appears broken at the water surface because the more dense water slows the motion of the light waves more than does the less dense air. The amount a light ray bends when passing from one type of matter into another is controlled by the index of refraction between the two substances for that wave length. The index of refraction of a transparent material is the comparison of the velocity of a light wave in a vacuum and the velocity of a light wave in the material. Refraction is important in making all kinds of optical instruments. The amount or degree of refraction depends on the wave length of the light. An example of this effect is the separation of a beam of light by a glass prism into its component colors. Each color has a different wave length, and each is refracted a different amount as it passes into and out of the prism (Beiser, 1973; Besancon, 1966; Callister, 1991; Hewitt, 1989).

Parallel Light Waves. All light consists of waves that vibrate at a very fast rate. One ray of light is made up of many waves that vibrate in all directions, but always perpendicular to the direction of the ray. A ray of light travels at a speed of approximately 186,000 miles per second. Sometimes it is desirable to confine the light wave vibrations to the same direction. By passing light through crystals and other materials, light becomes changed so that all of its waves vibrate in the same direction. These materials prevent light waves from vibrating in one direction, but do not hinder the vibrations in another direction. The components of the light waves that vibrate in one direction are allowed to pass through, while other waves are kept back. The resulting light is composed of parallel waves and is called polarized light (Hewitt, 1989; Longhurst, 1967). Polarized light has been used in drapemeters to minimize diffused light and thereby project clear shadows of drape diagrams (Collier, 1991; Collier et al., 1988; Chu et al., 1950; Cusick, 1968).

The Influence of Black Interior for the Modified Drapemeter

Different kinds of surfaces reflect different amounts of light that falls upon them. The amount of light a substance reflects is called its reflectance. White paper reflects 85% of the light cast upon it. Ordinary black paint absorbs 96 to 98% of light that falls upon it and only reflects 2 to 4%. These represent the extreme conditions of light reflectancy. The light reflectancy of colors ranges between these two extremes. A colored surface may reflect 2 to 85% of the light that falls upon it (Born & Wolf, 1965). Clear surfaces, such as glass, reflect little light. The light that is not reflected by a surface of an object either passes through or is absorbed and heats the object (Hewitt, 1989).

Light is scattered in all directions when it falls on an uneven surface. When light shines on a rough surface, the rays are diffused or reflected in many directions. Polished surfaces reflect most of the light that strikes them (Hewitt, 1989).

Shadow Formation

A shadow is the darkness behind an opaque object subjected to light from an outside direction. The complete or perfect shadow of an opaque body is called an umbra, and is created when the direct light from the source of illumination is cut off. An umbra, or sharp shadow is created by either a large faraway light source or a small nearby light source. Careful examination of many sharp shadows reveal that the light intensity near the boundary varies rapidly, but continuously, from darkness in the shadow to lightness in the illuminated region. The sharp shadow appearance is outlined by bright and dark bands called diffraction fringes (Born & Wolf, 1965; Hewitt, 1989). If the light source is nearby and larger than the object, the shadow directly behind the object is darker than the rest of the shadow. The darker portion of the shadow is the umbra. The space where part of the light is cut off (lighter shadow) is called the penumbra. If a ball is hung in front of a candle, light bends around the ball to form a light spot in its shadow. Diffraction is the spreading out of waves as they pass around an obstacle or through a hole or other opening. The spot is caused by the diffraction of the light waves as they pass around the edge of the ball. The center of the shadow is equally distant from all parts of the edge of the ball. Thus, the bent light waves arrive there at the same time, and unite to give light in the same phase. The rest of the shadow is dark because different diffracted light waves would have different distances to travel to get to any other point. Some rays fall behind and interfere with others. These rays cannot produce light because they are not in the same phase when they arrive (Hewitt, 1989).

Creating a Sharper Shadow Image

Rays of light always bend outward and expand as they pass around obstacles or go through an opening. The proprogation of light from a source begins as an infinite number of rays. The rays generally dissipate so that a finite number of rays pass through any point of a medium. In special cases the point may be found through which an infinite number of rays pass; such a point is said to be a stigmatic or sharp image. In the ideal optical instrument every point of a three-dimensional region, called the object space, will create a sharp image. The image space is defined by the totality of its image points. Corresponding points of the two spaces are said to be conjugate points. In general, not all the rays which proceed from the light source will reach an image space. Some of the rays will be excluded by diaphragms of the instrument. If every curve of an object space is geometrically similar to its image, the imaging between the two spaces is perfect (Born & Wolf, 1965).

Incandescent Light Bulb

Incandescent filament bulbs are available in many shapes. Lamp bulbs may be clear, lightly frosted, or so heavily frosted that the filament is completely obscured. Frosting on the bulb diffuses light so that rays travel at dispersed angles from the source. The glass bulb forms a vacuum encasing various parts which make the bulb operational. The part of greatest interest is a filament of metal which is heated to a glowing point. Generally a tungsten wire is supported by molybdenum wire to form a filament within an incandescent bulb. The tungsten filament is usually coiled to reduce loss of heat by convection. Platinum, carbon, tantalum, and tungsten have been used for filaments. Filaments may be linear or form flat compact grids. Bulb wattages range from less than one watt, in lamps smaller than a grain of wheat, to 10 kW for film studio floodlamps (Stevens, 1969).

Fresnel Lens

A lens is a transparent object that has at least one curved surface. Lenses are generally used to magnify or reduce images. Most lenses are made of glass, but any transparent material such as plexiglass may be used. Every lens has two principle foci, one on each side of the lens, because light rays can either enter or emerge from the lens parallel to the principle axis. The principle axis is a line perpendicular to the center of the lens. The distance of these foci from a simple thin lens is called the focal length of the lens. A light ray passing through the center of a thin lens keeps its original direction. A light ray striking at any other point is turned by an amount that increases with the ray's distance from the center of the lens. Rays that enter a lens parallel to its principle axis emerge along a line going through its principle focus (Meyer-Arendt, 1972).

In the case of a convex lens, the real image formed is smaller than the original object if the original is more than twice the focal length from the lens. But the real image will be larger than the object if the original object is at a point more than, but not twice, the focal length away. If the original object is less than a focal length away, a virtual image larger than the original image is formed (Hewitt, 1989).

Simple lenses cannot form sharp, undistorted colorfree images over a wide field because of defects. Such defects are corrected by using combinations of lenses. Anastigmatic lenses correct a tendency of single lenses to distort straight lines. A composite of convex lenses which have been sliced to create a flat surface theoretically form a fresnel lens (Meyer-Arendt, 1972).

A fresnel lens is a flat, thin piece of acetate butyrate in which are molded a series of small concentric stepped zones. These zones extend from the center to the outer margins. The fresnel zone plate acts as a lens with multiple foci. Each groove is a minute refracting facet capable of bending light apart. Its transmittance (ability to pass light) is greatly increased over that of a conventional lens of the same focal length. These zone lines are separated by only a few thousandths of an inch. Each concentric line acts as a part of the lens. Taken all together the zones form the function of a true lens. Fresnel lenses are used as an image and light concentrator in overhead projectors (Banerjee & Poon, 1991; Meyer-Arendt, 1972).

Conclusions

How a textile will drape from the support surface of a human body affects the design and silhouette of garments constructed from the textile (Cusick, 1962 cited in Hearle 1969; Deschamps & Ceith, 1985; Moore, 1992). Apparel designers need to be able to predict the drape of a fabric during the planning phase of garment design. In preparing patterns for some garments it is necessary to actually drape the proposed fabric on a human model. The fabric draping method of patternmaking is preferred for precision in very fitted styles and for aesthetics in softly, draped styles (Amaden-Crawford, 1989). Because this ability to predict the drape of textiles is so important to the apparel industry, many people have investigated fabric drape with a variety of approaches (Amirbayat & Hearle, 1989; Chu et al., 1950; Chu et al., 1960; Collier, 1991; Collier et al., 1988; Collier et al., 1989; Cusick, 1965; Dowlen, 1976; El-Bayoumi, 1980; Gaucher et al., 1983; Hearle, 1969; Hearle & Amirbayat, 1986; Lindberg et al., 1960; Moore, et al., in press; Postle & Postle, 1992, 1993; Sudnick, 1972).

A goal of the apparel industry is to develop a complete computer integrated manufacturing (CIM) process in order to service customers more quickly and reduce storage of inventory (Harlock, 1989; Jayaraman, 1990). The apparel design phase continues as a gap in CIM systems and continues as a need for further investigation (Harlock, 1989; Shishoo, 1990a, 1990b). Many of the apparel design processes, such as fashion illustration, pattern drafting, flat-pattern methodology, pattern size grading, and marker generation have been introduced as computer graphic programs. Some of these computer graphic simulation programs will integrate with other computerized apparel manufacturing processes (Lee & Steer, 1991; Waddell, 1992). The fabric drape method for patternmaking needs to be developed in order to close the gap in creating a complete CIM system for apparel manufacturers (Collier & Collier, 1990). In order to develop a computer program for graphic simulation of patternmaking by the fabric drape method, a computer program for graphic simulation of fabric drape must be developed.

Although many methods and devises have been developed for measuring fabric drape, neither ASTM or AATCC have consensus method for fabric drape testing. The accepted protocol in common use specifies a 10 inch fabric specimen and the FRL drapemeter. The fabric support platform of the FRL drapemeter is a stationary 4 inch diameter circle (with no edge curvature) held 5 inches above a fresnel lens. A light source beneath the fresnel lens projects the shadow of the draped fabric specimen to a clear tracing surface 1 inch above the support platform.

For the purpose of this study fabric drape is defined as the extent to which the unsupported portion of a textile will deform when allowed to hang under its own weight (Hearle, 1969; Sudnik, 1972). If the support surface remains the same, the unsupported portion of the textile specimen increases (drape overhang) as the specimen size increases. Thus, gravity has a greater influence on fabric drape for increased specimen sizes placed on the same surface. The mass (weight) of a fabric specimen reacts to the force of gravitational pull causing the unsupported portion of fabric to drape (Hearle & Amirbayat, 1986). The stiffness of a fabric exerts resistance to gravitational pull. The geometry of a textile also affects its resistance to deform or bend (Grosberg, 1969). Several investigators have correlated fabric bending and shearing properties with fabric drape values (Brown et al., 1990; Collier, 1991; Cusick, 1965; Dowlen, 1976; Gaucher et al., 1983; Ghosh et al., 1990a, 1990b, 1990c; Hearle, 1969; Lindberg et al., 1960). Other researchers have correlated hand values to fabric properties values obtained at low stress. Since fabric drape is a component of total fabric hand, these researchers suggest that the same fabric properties values can be used to predict fabric drape as well as how a fabric will cut, sew, and wear (Ayada, Miki, & Niwa, 1991; Curiskis & Taylor, 1990; Shishoo, 1990b).

Since many fabric properties are assessed before a fabric becomes a tool for apparel designers, it is possible to create a data bank of these fabric properties. The data bank can serve as a base for variables in calculations which predict fabric drape (Deschamps & Ceith, 1985; Harlock, 1989). In 1990 Collier emphasized a need for further research in predicting the deformation of fabrics during draping because the shapes formed by different fabrics due to support surfaces and gravitational forces could be assessed during the initial design phase. Dhande et al. (1993) developed a model using intrinsic geometry to predict fabric deformation. The focus of their study was to use intrinsic geometry parameters and fabric mechanical properties as inputs for simulating fabric drape. Previous studies have not used fabric property measurements as variables in computer graphic simulation of fabric drape. Fabric bending properties formed the variable base for the computerized geometric models generated for draped fabric surfaces. Dhande et al. (1993) also explored the geometries of a variety of fabric support surfaces. The geometric models were generated to render several surfaces similar to the apparel support surfaces on the human body with the intent of using the method as a predictive tool for apparel designers (Dhande et al., 1993). In order to continue research with geometric modeling of draped fabric surfaces Dhande et al. (1993) expressed a need to compare photographs obtained from drapemeter experiments with fabrics draped on a variety of surfaces representative of the human body to their computer graphic simulations. Dhande et al. (1993) also stated a need to compare resultant computer graphic simulations with photographs obtained from drape tested fabric samples with overhang lengths greater than those of standard drape testing protocol.

Thus, there is a need to construct a drape testing apparatus that can provide comparison objective measurements and needed photographs for continuing the research of Dhande et al. (1993). This fabric drape testing apparatus (drapemeter) needs to measure textile specimens of varying overhang lengths supported by platform surfaces of various shapes and sizes. The platform surfaces need to closely relate to surfaces composing the human body. This review of literature has not identified any research that has been conducted involving the use of fabric drape platforms which have different shapes or edge curvature.

CHAPTER 3: THEORETICAl FRAMEWORK

Hand, of which drape is a major component, involves the whole fabric as it is manipulated. Draped fabric interacts with body contours and air space as it assumes its own three-dimensional form. A fabric is appraised as having good draping qualities when the effect is pleasing to the eye, but this is a subjective observation and is difficult to measure. Researchers have sought to devise objective measurements that correlate with subjective measurements.

Current technology is moving toward computer simulation of fabric drape. Drape is a complex property of fabric influenced by fabric geometry and inherent properties such as stiffness and shear resistance. Sudnick (1972) defines drape as "the extent to which a fabric will deform when allowed to hang under its own weight" (p.14). The most common method for measuring drape involves the FRL drapemeter but previous research suggests that the parameters of this test may need to be expanded.

The effects of different fabric overhang lengths by altering either the diameter of the fabric specimen or the support platform have been investigated. Based on previous findings (Collier, 1991; Collier et al., 1988; Cusick, 1968; Sudnick, 1972) a need was indicated to conduct more studies on fabric drape overhang lengths. In order to study fabric overhang lengths greater than 3 inches a taller drapemeter than the FRL is needed.

After reviewing various means for relating fabric shear property measurements to fabric drape, the study by Collier (1991) indicated a strong relationship between fabric shear hysteresis and fabric DV. Thus, in order to measure the shear hysteresis of each fabric used in this study, there was an indicated need to use the KES-FB tensile and shear tester.

The drape coefficient is generally derived from data collected from a FRL drapemeter, where the specimen support system and specimen size are held constant. Drape coefficients are determined by protocol in common use published as testing procedures for the FRL drapemeter. Drape values distinguish quantification of fabric drape when standard measurement protocol is altered. The DV does not refer to an inherent fabric property but to a measurement of a fabric property.

Dhande, Rao, Tavakkoli, and Moore (1993) developed a computer graphics model using intrinsic geometry to simulate fabric deformation. The focus of their computer simulation project was to use intrinsic geometry parameters and fabric mechanical properties to simulate fabric drape from the human body. Previous studies have not used fabric property measurements to affect computer simulation of fabric drape. Dhande et al. have used the concepts of intrinsic geometry parameters to develop computerized geometric models of draped fabric surfaces based on fabric bending properties. They have also explored the geometries of a variety of fabric support surfaces. The geometric models have been generated to render several surfaces similar to the apparel support surfaces on the human body with the intent of using the method as a predictive tool for apparel designers (Dhande et al., 1993).

In working towards the development of a computer simulated model for demonstrating different fabrics draped on a three-dimensional human figure, a modified version of the FRL drapemeter was needed. Since many apparel parts require a variety of support geometries and a variety of fabric overhang lengths, there was a need to construct a fabric drape testing apparatus (such as a drapemeter) that could measure fabrics of different overhang lengths supported by different shaped platforms. Shaping of platforms would gradually work toward representation of 3D human body surfaces. Fabrics draped from these surfaces would produce objective quantification representating apparel contours on the human body. Measurements from the modified drapemeter would be used along with other mechanical property values of fabrics to provide data for the computer simulation model. Computer graphics simulating apparel design with fabric draping would be based on measurements of a variety of fabrics, in a variety of overhang lengths supported by different geometrical surfaces. These measurements may successfully predict fabric drape from different body areas such as the shoulder, waist, and neckline using an array of fabrics.

Cary and Sproles (1978) developed a framework for guiding test method development. The framework is composed of three levels. The first level relates to the utility of a test method. The second level describes the concepts of validity, reliability, manageability, and essentiality of a test method. The third level comprises objective and subjective means for evaluating level two components (Cary & Sproles, 1978).

Cary and Sproles (1978) define utility as an aggregate measure of theoretical and practical applicability for measuring a defined property of a product. If each of the level two components are acceptable, then the test method can be considered useful. In other words, levels two and three must be established in order to establish level one. Utility is established if there is scientific merit for measuring a particular property, if the method for measurement of the particular property is simple and parsimonious, and if the measurement results are meaningful and relevant to those who are affected by their use.

In order to continue development of computer simulation of the drape method for apparel designers, it was necessary to obtain objective draping data from larger fabric specimens than used on the FRL drapemeter. Preliminary experiments were conducted with the FRL Drapemeter and then several cardboard prototypes of a modified drapemeter were built. Many of the rationale statements were formulated after these preliminary experiments because it was determined that the FRL Drapemeter could not test fabric specimens with diameters larger than ten inches. The initial cardboard prototypes suggested that it was possible to build a drapemeter that could measure larger fabric specimens. After the final cardboard prototype drapemeter was constructed with proposed modifications, further preliminary experiments provided foundation for further research.

Research Problem

This research was part of an overall project to simulate fabric drape on a manikin through a computer graphics program using an intrinsic geometry model. Developing the modified drapemeter was one step in working toward computer graphics simulation of 3D fabric draping surfaces as they would fall over the various surfaces of the human body. In this study a modification of the FRL Drapemeter with interchangeable pedestals and platform disks was developed in order to investigate the effects of fabric overhang length, platform disk shape, and disk edge curvature on the drape coefficients and values of two plain weave apparel fabrics.

Objectives for this study were:

1. to develop a modified drape testing instrument with interchangeable pedestals of different heights and platform disks of circular and oval shapes with sides or edges having different radii of curvature
2. to determine if the modified drape testing instrument will project drape shadows which will equal or exceed the accuracy of the FRL drapemeter

3. to investigate the independent effects of fabric overhang length, platform disk shape, and disk edge curvature on node counts and drape coefficients or drape values of two plain weave apparel fabrics in five specimen sizes.

Criteria for Objective 1

The following criteria guided the development of the modified drapemeter. A preliminary prototype was used to determine specific measurements for the modified drapemeter.

a. Information concerning larger fabric specimens than the FRL drapemeter will accommodate was needed for the computer simulation project.

   Rationale. The modified drapemeter should have dimensions to accommodate specimens up to 45.72 cm (18 inch) diameter.

b. The modified drapemeter should accommodate pedestal heights of 12.7 cm (5 inches) to 58.42 cm (23 inches).

   Rationale. In order to compare the modified drapemeter with the FRL drapemeter a pedestal with a minimum height of 12.7 cm (5 inches) was needed. The drapemeter was planned so that the tallest pedestal could be 58.42 cm (23 inches) in height. (This 58.42 cm (23 inch) high pedestal would support a size 14, half-scale body form from waist down so that skirts could be placed on it and measured for drape.)

c. Fabric support platforms needed to be of different shapes and be interchangeable.

   Rationale. If the human body was sliced horizontally, there would be more oval shapes than circular ones. The neck, shoulders, waist, and hip sections are examples. If a drapemeter is to test fabric drape as it would hang from the human body, the drapemeter would need to have an oval draping platform.

d. Fabric support platforms needed to have different edge curvature and be interchangeable.

Rationale. The human body does not have 90 degree transitions from the waist to hip area. The transitional curve of the female waist to hip area is more closely related to curved edged platforms.

e. The modified drapemeter needed to produce collimated light and extraneous (non-collimated light) light needed to be blocked or absorbed.

Rationale. Based on light theory, in order to get a clear shadow projection, light should be collimated and extraneous light should be blocked or absorbed.

f. The modified drapemeter needed to have pedestals and fabric support platforms that allowed operators to reproduce results obtained with the FRL drapemeter.

g. The modified drapemeter needed to be simple and comfortable during use for the operator.

h. The modified drapemeter would use electricity to provide power for the light source.

i. The modified drapemeter needed to fit in available laboratory space.

j. The modified drapemeter needed to be a permanent structure that could withstand atmospheric conditions and continuous use.

Research Hypotheses

Research Hypotheses I, II, III, and IV addressed objective 2 by testing the accuracy and reliability of the modified drapemeter. Research Hypotheses V, VI, and VII addressed objective 3.

Research Hypothesis I. Shadows of cardboard circles obtained from the modified drapemeter will equal or exceed the accuracy of cardboard shadows obtained by the FRL drapemeter.

Rationale. When the modified drapemeter was adjusted so that pedestal height and platform disk were similar to those in the FRL drapemeter, it appeared logical to believe that projected shadows obtained from both drapemeters would be similar.

Research Hypothesis II. The modified drapemeter will replicate drape values obtained with the FRL drapemeter when using the same instrument parameters.

Rationale. Since the FRL drapemeter is the drape testing instrument in common use, modified drape testing equipment should not sacrifice the accuracy of obtainable shadow projections.

Research Hypothesis III. The modified drapemeter will replicate drape values obtained with the FRL drapemeter when using three pedestal heights.

Rationale. Since the FRL drapemeter is the drape testing instrument in common use, modified drape testing equipment should not sacrifice the accuracy of obtainable shadow projections.

Research Hypothesis IV. Projected shadows obtained with the modified drapemeter will be have measurement repeatability.

Rationale. Since the FRL drapemeter is the drape testing instrument in common use, modified drape testing equipment should not sacrifice the measurement repeatability of obtainable shadow projections.

Research Hypothesis V. Length of fabric overhang from the four-inch diameter platform disk with no edge curvature will influence node counts and drape values obtained from measurements of two medium weight woven fabrics.

Rationale. Newton's law of universal gravitation states that all mass has an attraction to all other mass (Hewitt, 1989). When this law was applied to the fabric overhang, which is the unsupported part of the fabric specimen, it was logical to believe that the longer the fabric overhang, the greater would be the unsupported mass that could be attracted to an even greater mass, the earth. Further reasoning suggested that the more gravitational pull affecting the drape of the fabric specimen, the smaller would be the drape diagram and the smaller would be the drape value.

Research Hypothesis VI. The shape of the platform, oval versus round, will influence node counts and drape values of two medium weight woven fabrics.

Rationale. Comparisons of photographed drape diagrams of skirts worn by manikins and drape diagrams of circular specimens on circular platforms indicated a more oval shape in the diagrams of the skirts (Moore, Gurel & Lentner, in press). Observation of diagrams drawn of circular specimens supported by a circular platform and oval specimens supported by an oval platform suggests a negative correlation between area supported and size of drape diagram. Since more area of the specimens will be supported when the oval platforms (4 X 5 inches) as opposed to circular platforms are used for testing, it was logical to predict that drape diagrams would be larger in area and more oblong in shape.

Larger drape diagrams do not indicate larger drape values since the supported area is subtracted during calculations of the drape value. Previous studies have indicated strong correlations between drape diagrams and drape coefficients obtained from the same specimens (Chu et al., 1950; Collier, 1990; Dowlen, 1976).

Research Hypothesis VII. The curvature of the edge of the platform will influence node counts and drape values of two medium-weight woven fabrics.

Rationale. Fabric specimens draped from a platform with a curved edge are supported for a similar distance but through a transitional termination of support. Through logical deduction it was believed that the deformation that occurs at the platform edge would be caused by the more gradual shearing of the fabric specimen; thus a larger drape diagram, a lesser node count, and a larger drape value should be obtained.

Definitions

Theoretical Definitions

Accuracy: The degree of agreement between the true value of the property being tested (or an accepted standard value) and the average of many observations made according to the test method, preferably by many observers (ASTM D 123-91a, 1990, p.12).

Characteristic: A property of items in a sample or population which, when measured, counted, or otherwise observed, helps to distinguish between the items (ASTM D 123-91a, p.17).

Deformation: A change in shape of a material caused by forces of compression, shear, tension, or torsion (ASTM D 123-91a, 1990, p.21).

Drape: The extent to which a fabric will deform when allowed to hang under its own weight (Sudnik, 1972, p.14).

Drape (Shadow) Diagram: Projected shadow of draped fabric specimen that occurs during drape testing.

Drapemeter: A form of overhead projector using a fresnel lens and a light source. The instrument provides a simple method of measuring the property of fabric drape by projecting the shadow of a fabric specimen which is partially supported by a platform. Results are reported as drape coefficients or drape values.

Fabric Bending Length: A measure of the interaction between fabric weight and fabric stiffness as shown by the way in which a fabric bends under its own weight. It reflects the stiffness of a fabric when bent in one plane under the force of gravity, and is one component of drape. D 1388 (ASTM D 123-91a, 1990, p. 14).

Fabric Count : The number of warp yarns (ends) and filling yarns (picks) per unit distance as counted while the fabric is held under zero tension, and is free of folds and wrinkles (ASTM D 123-91a, 1990, p.19).

Fabric Geometry: The relationship, or interrelationships, of fibers and yarns to their ultimate shape and arrangement in the finished fabric. (Joseph, 1986, p. 355).

Fabric Hand: The tactile sensations or impressions which arise when fabrics are touched, squeezed, rubbed, or otherwise handled. (AATCC Technical Manual, 1991, p. 330).

Fabric Overhang Length: The part of a fabric specimen that is not supported by a platform in a drapemeter.

Fabric Shear: Movement of adjacent sets of yarn at the intersections in fabric constructions so that cloth is changed in shape by intersecting yarns shifting from a 90 degree position.

Focal Point: Point at which light rays parallel to the axis of a mirror or lens come to focus. (Hewitt, 1989, p. 712)

Focus: Point at which straight lines intersect. (Hewitt, 1989, p. 712)

Fresnel lens: Overall flat lenses bearing concentric grooves with surface segments resembling, and parallel to, a conventional lens surface (Meyer-Arendt, 1972, p.202).

Nodes: Projections created when fabric buckles or undergoes double curvature.

Pedestal: A vertically placed rod or post that centrally supports the fabric support platform in a drapemeter.

Plain Weave Fabric: A fabric pattern in which each yarn of the filling passes alternately over and under a yarn of warp and each yarn of the warp passes alternately over and under a yarn of the filling (ASTM D 123-91a, 1990, p.37).

Platform: The horizontal surface supported by the pedestal in a drapemeter on which specimens are positioned for testing.

Operational Definitions

Drape coefficient: The percentage of the area of the annular ring of fabric (less the supporting ring) obtained by vertically projecting the shadow of the draped fabric specimen (less the supporting ring). The theoretical range is zero to 100%. (Dowlen, 1976, pp.1-2). In this study Drape Coefficient was used to present results obtained by standard measurement protocol for the FRL Drapemeter. The Standard protocol specifies a circular fabric specimen of 10 inch diameter and a circular fabric support platform with a 4 inch diameter and no edge curvature. The platform is supported by a pedestal which measures 5 inches in height.

Drape Value: The percentage of the area of the annular ring of fabric (less the supporting ring) obtained by vertically projecting the shadow of the draped fabric specimen (less the supporting ring). The theoretical range is zero to 100%. (Dowlen, 1976, pp.1-2). In this study Drape Value was used to distinguish quantification of fabric drape when standard measurement protocol for the FRL drapemeter was altered.

Fabric bending length: The cube root of the ratio of the flexural rigidity to the weight per unit area. D 1388 (ASTM D 123-91a, 1990, p. 14).

Assumptions

1. The modified drapemeter is of sound construction.
2. Supplier's (Testfabrics, Inc.) identification of fiber content and fabric finishes is as stated on the label.

Limitations

1. The sample was limited to fifteen corrugated cardboard circles and two plain weave fabrics.
2. The sample and traced diagrams were limited by the possibility of human error in tracing and cutting.
3. Dimensions of the modified drapemeter were limited to the 19 inch by 24.75 inch measurements of fresnel lens.

CHAPTER 4: PROCEDURES OR METHODS AND MATERIAIS

Development of Modified Drapemeter

The first part of this chapter relates to objective 1, which addresses the development process of the modified drapemeter. The last part of this chapter relates to objectives 2 and 3, which address empirical evidence related to the accuracy and reliability of the modified drapemeter. The modified drapemeter required some test method protocol adjustments due to interchangeable fabric support platforms; however, general drape testing was conducted according to current methods used with the FRL drapemeter. Also, a method was developed for calibration of the modified drapemeter. Thus, the first two recommendations of the Cary and Sproles (1978) guide were applied to this study (Figure 1).

Rationale for Modification of FRL Drapemeter

In order to continue development of computer simulation of the drape method for apparel designers, it was necessary to obtain objective draping data from larger fabric specimens than used on the FRL drapemeter. Preliminary experiments were conducted with the FRL Drapemeter and then several cardboard prototypes of a modified drapemeter were built. Many of the rationale statements were formulated after these preliminary experiments because it was determined that the FRL Drapemeter could not test fabric specimens with diameters larger than ten inches. The initial cardboard prototypes suggested that it was possible to build a drapemeter that could measure larger fabric specimens. After the final cardboard prototype drapemeter was constructed with proposed modifications, further preliminary experiments provided foundation for further research rationale statements.

	ACCURACY,..................	RESEARCH HYPOTHESES I and III
	VALIDITY,	STATISTICAL HYPOTHESES Ia, Ib, and III
	LACK OF BIAS	
UTILITY }	RELIABILITY,..................	RESEARCH HYPOTHESES II and IV
	PRECISION	STATISTICAL HYPOTHESES II, IVa, IVb, IVc, and IVd
	MANAGEABILITY...........	INTERVIEW
	ESSENTIALITY................	INTERVIEW

Figure 1. Schematic Diagram Relating Model by Cary and Sproles (1978) to Objective 2.

The FRL Drapemeter (Figure 2) has a stationary pedestal and platform which limits the size of fabric specimens to be tested. It was predicted that a taller pedestal was needed to accommodated a larger specimen; thus, a larger box was needed to accommodate the taller pedestal and larger specimens. Since it was also necessary to compare the accuracy of a modified drapemeter to the FRL Drapemeter, a drapemeter was needed that would accommodate pedestals of various heights and specimens of various sizes, including those of the FRL drapemeter.

Since the computer simulation program will be draping a variety of fabrics on a body form, a means for measuring fabric drape as it is supported by oval body areas and curved body edges was needed. It was determined that a drapemeter could be built that would accommodate changes in platform shapes, and platform edges so that the affect of these platform changes on fabric drape can be studied.

Preliminary experiments determined that the placement of the top shelf should be stationary for tracing of shadow diagrams, and the shelf supporting the pedestals should be adjustable to accommodate various heights. A distance of 1/2 inch between the platform and the tracing shelf was found to provide a projected shadow with the most clarity when specimens were placed on the platform. It was determined that projected images were more accurate in size and clarity if the walls and floor of the modified drapemeter were painted flat black and the door was kept closed during shadow tracing. (Flat white paint has a reflectance of 85%, and flat black paint has a reflectance of 2 to 4% (Born & Wolf, 1965)).

<u>Procedures for Constructing a Prototype of the Modified Drapemeter</u>

A prototype drapemeter of cardboard was constructed before beginning the plexiglass model. A rectangular cardboard box was assembled from pre-cut 275 ounce per square inch

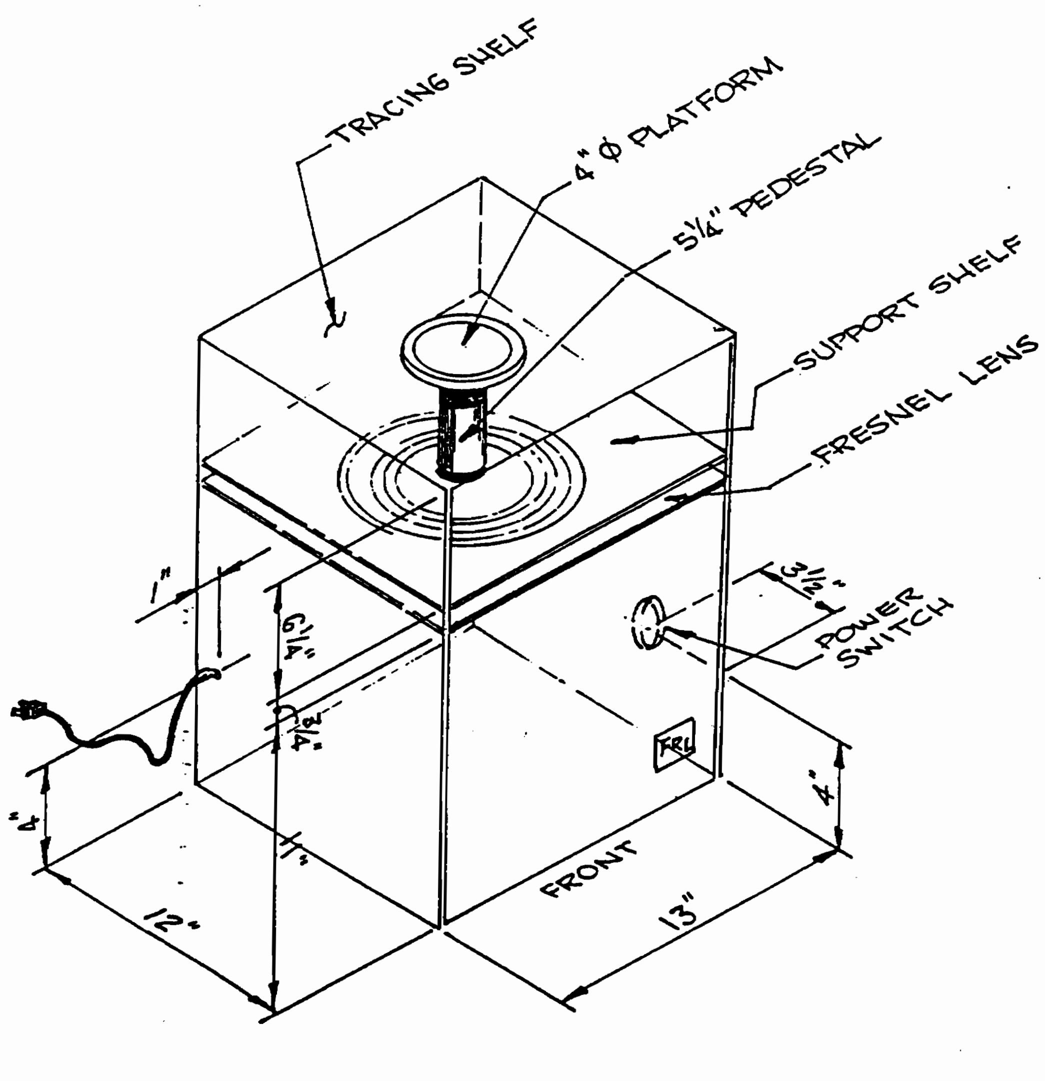

Figure 2. Scale Drawing of FRL Drapemeter.

test corrugated, double thick cardboard. The box measured 60 X 26 X 20 inches. Sides were glued and taped together. All sides were painted flat black inside and outside. Wooden strips painted flat black were glued in predicted placements to support the fresnel lens and plexiglass shelves. The front side panel was scored with an exacto knife to form a door that would bend to the outside and downward. This door allowed for the adjustment of light bulbs, the fresnel lens, and both plexiglass shelves. The light source was located in the bottom of the box. The fresnel lens was placed about 30 inches above the light source. Above the fresnel lens, a plexiglass shelf supported a pedestal of PVC pipe. The pedestal supported a circular platform of plexiglass measuring 1/2 inch thick and 4 inches in diameter. There was another plexiglass shelf covering the top of the box which supported the tracings of projected shadows. The door was opened when making adjustments and for placing objects on the platform that were projected to the top shelf for tracing. The door was closed during the tracing process for the preliminary experiments.

A thick styrofoam block supported the light source and served as the bottom of the prototype. The precut expanded polystyrophene block measuring 6 X 22 1/2 X 26 inches was painted flat black. A wooden plank measuring 1 X 6 X 11 inches was painted flat black and glued to the center of the styrofoam block. A ceramic lamp socket was wired and mounted to a wooden plank. For safety and convenience a toggle switch was attached to the wiring. This styrofoam block could be adjusted similar to the movement of a piston by moving up and down on wooden block supports.

Four light bulbs were purchased for preliminary experimentation. All four bulbs were of clear glass but different watts. The 60 watt bulb was round with a short, wide filament. The filament measured 3 inches high. The 100 watt bulb was of standard form with a 4 inch high filament. The 200 watt and 300 watt bulbs were taller versions of the standard 100 watt bulb. Both the 200 watt and 300 watt bulbs had tall and narrow filaments measuring 6 inches high. All bulbs were held in both vertical and horizontal positions for preliminary experiments.

In this study light was focused for obtaining distinct drape shadow diagrams by a fresnel lens. A focal point of 24 inches was stated for the fresnel lens by the manufacturer. The focal length was found to be the number of inches between the center of the fresnel lens and the top of the filament in an incandescent light bulb.

A fresnel lens measuring 19 X 24 3/4 inches was purchased from Edmund Scientific. This fresnel lens was 1/8 inch thick with 50 concentric lines per inch. Descriptive characteristics included a refractive index of 1.49 and a transmission of 92% of the visible light spectrum ranging from 400 to 700nm. To determine the exact focal point distance of the fresnel lens a test was conducted outdoors at noon on a clear, sunny day. The lens was held in a horizontal position above an asphalt surface and its height adjusted until a perfect point of light was focused on the asphalt surface. The distance between the fresnel lens and the pavement was measured. This distance was in agreement with the 24 inch focal length advertised by Edmund Scientific.

Two 20 X 25 inch shelves were cut from plexiglass sheets which originally measured 48 X 96 X 1/4 inches. One shelf was used to support temporary pedestals cut from PVC pipe. The other shelf was used to support tracing of projected shadows. A 3 X 5 inch index card and cardboard circles with diameters of 10, 14, and 18 inches were used to determine shelf placement and best light source.

The following conclusions drawn from preliminary experiments with the prototype were used to plan construction for the modified drapemeter. (a) The critical distance for spacing the fresnel lens from the light source was found to be 22 to 24 inches from the filament of the light bulb. (b) It was determined that the 60 watt round bulb was the best source of light. (c) Piano hinges were selected for allowing the wide sides of the box to open in order to avoid cracks for light to escape. Placement for the hinges was determined to be best at the level of the fresnel lens so that the lens could be removed and cleaned and the light bulb could be changed. (d) Critical distance for specimen accuracy was found to be from the lens to the lower edge of fabric specimen in drape formation, not from the platform holding the specimen. This distance was determined to be accurate within 21 to 24 inches. (The tallest pedestal was planned to be 23 inches in height since skirts constructed for the half-scale manikin had 22 inch lengths from waist to hem. This 23 inch high pedestal would also support a body form of a size fourteen, half-scale manikin from waist down so that skirts could be measured for drape).

Procedures for Constructing the Modified Drapemeter

A modified drapemeter was built using the basic design features of the FRL drapemeter. The modified drapemeter was a taller box (54 1/2 inches) with more depth (20 inches) and width (26 inches) than the FRL drapemeter (Figure 3). Plexiglass was used to construct all the sides and shelves of the box. The narrow sides were cut from 3/8 inch thick plexiglass, and the wide sides and the bottom were cut from 1/4 inch thick plexiglass. Both shelves were cut from 1/4 inch thick plexiglass. Plexiglass parts were cut with a tablesaw and the edges were smoothed with a planer. The plexiglass sides, bottom, and top were joined by a solvent. About 20cc of Mallinckrodt dichloro-methane acted as solvent. A 30cc glass hyperdermic syringe with a 22 gauge needle was used to inject the solvent between plexiglass parts.

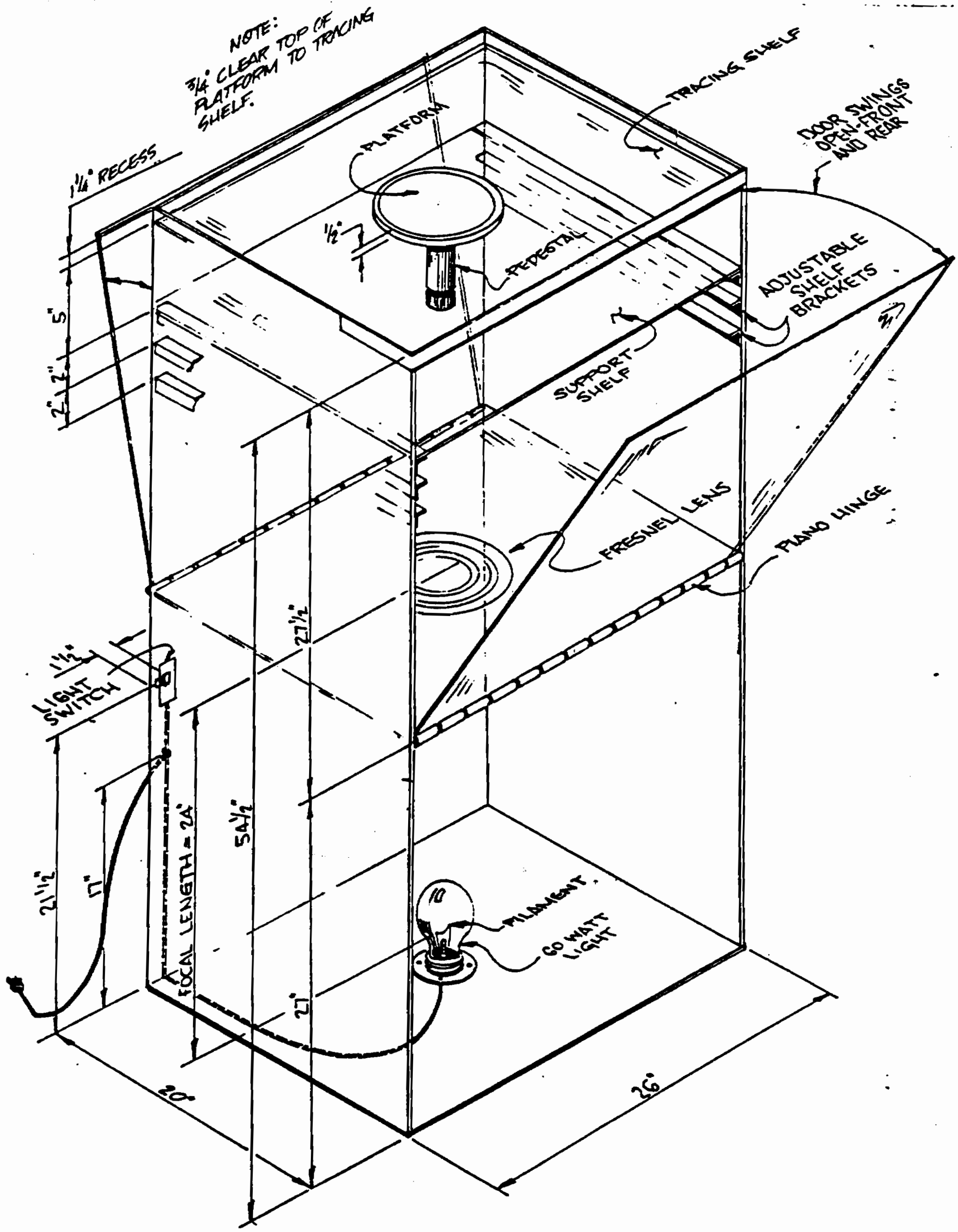

Figure 3. Scale Drawing of VPI&SU Modified Drapemeter.

Shelves were rendered adjustable by using standard metal shelving strips with slots every 1/2 inch and metal support brackets. The shelves slide into the box and rest on the metal support brackets. The framed fresnel lens also rests on metal support brackets. The lens is removable in order to facilitate cleaning and the replacement of light bulbs. Two metal strips were screwed to each narrow side of the modified drapemeter. Support brackets were placed for the fresnel lens, the top shelf, and in four positions for shelf adjustments that best accommodate the different pedestal heights. All plexiglass walls and the plexiglass floor were painted flat black inside and outside. Since paint will not stick to plexiglass, the paper that coats the plexiglass when purchased was left on the bottom and side pieces for paint adherence. The metal shelving assembly was also painted flat black.

Adjustable shelves and the fresnel lens were left clear. The wide walls were hinged with piano hinges to open out and downward. Screw holes for the hinges and shelf supports were drilled with a 3/8 inch Craftsman electric handdrill. Flat head slotted nuts were used to hold hinges and shelf supports in place.

The same wiring assembly used in the cardboard prototype was attached to the floor of the modified drapemeter. The switch was attached to the outside of one of the narrow walls. A hole was drilled near the bottom of a wall to allow the electric cord to snugly fit through it to be connected to an electric outlet.

Interchangeable parts constructed for the modified drapemeter included three pedestals of different heights and 10 platforms of two shapes (round and oval) and five edge curvatures with edge radii of 0, 1/16, 2/16, 3/16, and 4/16 inch.

Oval platform dimensions were determined by taking waist measurements from five size fourteen manikins. Four of the manikins were full human scale. One manikin was human half-scale. Four sewing measuring tapes were attached at the waist of each manikin, one at each side, one at center back, and one at center front. Calipers were used to take side-to-side measurements and front-to-back measurements. The measurements from the four human size manikins were divided in half for comparison with the half scale manikin. The mean of these measurements was used as the dimensions for sizing the oval platforms. For the oval platforms the 4 inch diameter referred to the front to back thickness measurement, and the 5 inch diameter referred to the side to side thickness measurement. Five oval platforms were cut 4 X 5 inches from 1/2 inch thick plexiglass. To cut the oval platforms, a pattern was drawn using a compass to draw two circles with 4 inch diameters placed with center points 1 inch apart. This pattern was traced on the plexiglass and cut with a bansaw enlarging the circumference 1/32 inch. (The extra 1/32 inch was removed during sanding.) Platforms were sanded to the traced line with a Rockwell vertical belt sander. This sander had a 16 inch belt with a grit of 120. Platforms were held in a 6 inch vise for edge curvature to be cut with a router. Center holes were drilled into each platform with a 1/4 inch diameter wood bit on a DoAll DV-16 drill press.

The caliper measurements of the size 14 manikin were also used for determining the degree of curvature for the platform edges or sides. Measurements were taken every 1/8 inch from the manikins' waist to two inches below the waist. These measurements were made side-to-side and front-to-back. Slopes were determined for every 1/8 inch.

Slopes were also found for other body areas. A flex curve was placed against a size 14 manikin then laid against graph paper. Slopes were determined for each change in curvature. A slope of 0.0625 was measured at the side, center front, and center back for waist-to-hips lengths on a size 14 manikin. Measurements taken from center shoulder over arm of a human revealed slopes ranging from 0.0625 to 0.25. Other shoulder measurements were taken on a size 14 manikin. The back shoulder curve from midpoint on the shoulder to shoulder blade had a slope range from 0.0625 to 0.25. The front shoulder curve was measured from the midpoint on the shoulder over the bust on the princess line. This curve had slopes ranging from 0.0625 to 0.25. The armscye curve ranged from 0.0625 to 0.25. The slope from neck down center neck measured on a size 14 manikin ranged from 0.0625 to 0.25 with 0.25 representing the curve closest to the neck.

Edge curvature was determined by relating the slopes found on the manikins to the difference in the circumferences of a platform top and bottom. Platform edge curvature radii ranged from 0/16 inch to 4/16 inch. Edge curvature was formed by using select bits in a Craftsman router.

Pedestals used to support the platforms were cut from a 1 1/4 inch diameter solid aluminum rod with a bansaw using a metal cutting blade having 14 teeth per inch. A lathe was used to flatten the ends. Centered holes were drilled and tapped for internal screw grooves on each end of all pedestals. A flute bolt, 1/4 inch in diameter and one-inch long, with 20 threads was used to hold the pedestal to the plexiglass support shelf. A similar bolt with a protruding socket cap was used to hold the platforms to the pedestals and act as a pin for holding drape specimens for measurement. Since an allen wrench was needed to change screws, a point was sharpened on one end so that a pin with a sharp point could be used for holding specimens.

The modified drapemeter was a vertical, rectangular box with a standard light socket and bulb in the bottom. A switch was connected to the lamp socket for controlling the light source. The bottom and sides of the drapemeter were painted black inside and outside. The paint was used to help collimate light needed to create the drape shadow diagrams. The modified drapemeter needed to produce collimated light and extraneous (non-collimated light) light needed to be blocked. Hinged doors opened on opposing upper sections to aid shelf adjustment and placing of fabric specimens for testing. These doors were always closed during drape shadow tracing. The doors were held closed with screen door latch hooks placed at each corner.

All shelves, including the top, were left unpainted and clear. The bottom most shelf support accommodated a metal frame holding the same fresnel lens used in the prototype. The next higher shelf was rendered adjustable to support various pedestals. Four sets of shelf support brackets were placed at heights determined best for each of the tested pedestals. Pedestals of different heights were interchanged by using a bolt attachment to secure them to the plexiglass support. Platforms were interchanged by means of a small centrally located hole in each platform. A bolt with a protruding socket cap fastened each platform to a pedestal. The protruding bolt was used to anchor fabric specimens during drape testing. The top of the box was another clear shelf of plexiglass. This fixed shelf was used for tracing projected drape shadow diagrams.

The 60 watt electric bulb used in the prototype provided a light source in the bottom of the plexiglass box. The black bottom and walls and the fresnel lens collimated this light to project a shadow of the specimen when placed on the platform. Clear plexiglass shelves allowed the projected shadow to be of high resolution and of equal size to the specimen. The projected shadows were traced on thin tracing paper placed on the top plexiglass shelf.

By using the basic design principles of the FRL drapemeter, a modified drapemeter was built. The modified drapemeter was a taller box with more depth and width than the FRL drapemeter. It accommodated larger parts and specimens by using adjustable shelf heights.

Empirical Testing of Modified Drapemeter

Objectives 2 and 3 of this study provide empirical evidence related to the accuracy and reliability of the modified drapemeter. Materials used in these analyses are described below. Methods are described for each research hypothesis.

Materials Used for Drapemeter Testing

Paper. Paper used for tracing the shadow diagrams measured nineteen by twenty-four inches. The paper is manufactured by Bienfang as part of its designer series of commercial art paper (parchment number 100). Since drape coefficients and drape values are dependent on weight comparisons of traced drape diagrams with paper cut to the size of the platform and the original sample, it was necessary to use the same paper throughout the study.

Cardboard. Double thick, 275 test corrugated cardboard in the study was purchased in two 100 X 50 inch sheets that had been precut in six panels. Cardboard circles were cut from two panels and were used to compare accuracy of the modified drapemeter with the FRL drapemeter. Circles were drawn with a precision compass and cut with an exacto knife. Cut cardboard edges were sanded. All circles were remeasured after sanding. Diameters of the cardboard circles ranged from 4 to 18 inches in one-inch increments. Cardboard circles were weighed before conditioning and after forty-eight hours in a standard environment to determine moisture take-up before testing. Weight gains of 0.1 gram for the 4 inch diameter circle to 5.6 grams for the 18 inch circle were contributed to moisture take-up by the cardboard.

Fabric. Plain weave fabrics were chosen in an attempt to limit fabric property variables and to isolate the effects related to the exchangeable parts of the modified drapemeter. Proposive sampling methods were used for choosing a sample of two woven fabrics. A proposive population sample requires certain criteria to be set; then the researcher systematically collects subjects that meet this criteria (Triola, 1986). Set criteria for this research involved the limitation to fabrics of plain weave and similar thread counts, medium weight, moderate stiffness, and less than 5% bow or skew. Plain weave fabrics with similar thread counts represent a small segment of the total fabric population. The many variables to be considered with a variety of fabric geometries required the necessity of limiting the fabric population in order to complete this research within time limitations. Plain weave fabrics with similar and fairly balanced thread counts were chosen for drape testing for two reasons. Pierce (1937) reported that asymmetrical weaves of varying lengths of float cause curling and other asymmetrical effects of tension. And after reviewing related literature, it was found that most drape testing was conducted on plain weave fabrics. In order to relate this research with past findings, it was necessary to confine sample fabrics to similar geometries.

Fabrics were obtained from Testfabrics, Inc. to represent a population of medium thickness and stiffness. One fabric was a polyester/wool blend. The other fabric was 100% cotton. The fabrics were conditioned and tested by ASTM and AATCC standard procedures for identifying characteristics before being used in drape testing. Specimens used in drape testing were cut from each fabric in circles of 10, 14, and 18 inch diameters and ovals of 10 X 11, 18 X 19 inch diameters. Two sets of oval specimens were cut in each size specification so that warp yarns were parallel to the long diameter in one set and parallel to the short diameter in the other set.

Fabric Characterization

Mean results from fabric characterization tests are in Table 1. Only the resultant means are reported.

Fabric characteristics for the two fabrics in the sample were measured using standard ASTM and AATCC test methods. All tests for fabric characterization except shear testing were conducted in a controlled environment, 70+/-2 degrees Fahrenheit and 65+/-2% humidity as recommended by ASTM D 1776-90. Fiber content was identified by supplier's (Testfabrics, Inc.) label. Fabric one was a polyester/wool blend (7509). Fabric two was of 100% cotton (477M). Fabric construction was identified by the supplier and by unraveling part of each specimen. This study was restricted to fabrics with plain weaves. Fabric bow and skew was assessed through ASTM Test Method D 3882-88. Yarn denier was measured using ASTM Test Method D 1059-87. Shear testing was conducted using a Kawabata tensile and shear tester at Texmac, Inc. located in Charlotte, NC. (The environment at Texmac, Inc. was not controlled. The temperature ranged from 73 to 77 Fahrenheit degrees, and the humidity ranged from 40 to 47%.) The Kawabata tester measured shear resistance at an angle of five degrees.

Fabric Preparation

Fabric specimens were conditioned in the controlled environment for 24 hours. The two fabrics were cut into circular specimens having 10, 14, and 18 inch diameters and oval specimens having 10 X 11 and 18 X 19 inch diameters. The oval specimens were cut in two sets, one set with the warp yarns parallel to the short diameter and the other set with the warp yarns parallel to the long diameter. A 1/4 inch diameter circle was cut in the center of each fabric specimen. This small centered circle allowed the specimens to be anchored during

Table 1. Fabric Characterization Results

Fabric Characterization Tests	Fabric One: Polyester/Wool	Fabric Two: 100% Cotton
Yarn count (w X f)* (ASTM D 3375-85)	54 X 57	47 X 49
Yarn twist, w (ASTM D 1423-88)	45.52 tpcm (17.92 tpi)	30.78 tpcm (12.12 tpi)
Yarn twist take-up, w (ASTM D 1423-88)	4.76%	4.76%
Yarn twist direction, w (ASTM D 1423-88)	s	z
Yarn twist, f (ASTM D 1423-88)	46.33 tpcm (18.24 tpi)	35.97 tpcm (14.16 tpi)
Yarn twist take-up, f (ASTM D 1423-88)	4.76%	4.76%
Yarn twist direction, f (ASTM D 1423-88)	s	z
Yarn crimp, w (ASTM D 3883-85)	12.14%	2.45%
Yarn crimp take-up, w (ASTM D 3883-85)	10.83%	2.39%
Yarn crimp take-up, f (ASTM D 3883-85)	6.93%	11.85%
Yarn crimp, f (ASTM D 3883-85)	7.45%	10.60%
Fabric weight (ASTM D 3776-85)	18.408 mg/cm2	18.430 mg/cm2
Bending length, w (ASTM D 1388-64)	2.238 cm.	2.509 cm.
Bending length, f (ASTM D 1388-64)	2.222 cm.	2.131 cm.
Fabric thickness (ASTM D 1777-64)	0.442 cm. (0.0174 inches)	0.043 cm (0.0170 inches)
Flexural rigidity, w (ASTM D 1388-64)	206.203 mg-cm	291.221 mg-cm
Flexural rigidity, f (ASTM D 1388-64)	201.914 mg-cm	178.414 mg-cm
Fabric shear, w	4.44 gf/cm	4.55 gf/cm
Fabric shear, f	4.26 gf/cm	4.77 gf/cm
Shear hysteresis, w	4.57 gf/cm	4.51 gf/cm
Shear hysteresis, f	4.29 gf/cm	4.62 gf/cm

*w = warp, *f = filling

drape testing by the protruding screw head which held platforms to the pedestal. Drape testing was conducted three times for each specimen for both face-up and face-down placements.

Methods Related to Research Hypotheses

Research Hypothesis I: Shadows of cardboard circles obtained from the modified drapemeter will equal or exceed the accuracy of shadows obtained by the FRL drapemeter.

All tracings were made by using the same weight of tracing paper purchased in a tablet of 100 sheets measuring 48.26 by 60.96 cm (19 by 24 inches). Both cardboard and tracing paper were stored in a controlled standard environment for 48 hours before testing.

Fifteen cardboard circles ranging from 10.16 to 45.72 cm (4 to 18 inches) in diameter were placed on tracing paper and traced with a vertically held pencil. The paper circles were cut out along the inner edge of the tracing line then weighed. Using the parts of the modified drapemeter that are most similar to the FRL drapemeter, drape diagrams were obtained by tracing shadows projected to the top plexiglass shelf. Seven cardboard circular specimens with diameters ranging from 10.16 to 25.4 cm (4 to 10 inches) were placed twice (face up and face down) on the 4 inch circular platform having 90 degree sides or edges. This platform was placed on the 12.7 cm (5 inch) high pedestal. A fresnel lens created collimated light which cast the shadow of the cardboard circle on the top shelf or tracing platform. A shadow diagram of the cardboard was traced by using a vertically held pencil. Shadow diagrams were cut out along the outside edge of the tracing line. Shadow diagrams from the modified drapemeter were compared to shadow diagrams from the FRL drapemeter in both area and weight.

The same cardboard circles were used to obtain drape diagrams with the FRL drapemeter. Because specimen diameters greater than 10 inches are distorted or unmeasurable on the FRL drapemeter, only shadow diagrams from cardboard specimens ranging from 10.16 to 25.4 cm (4 to 10 inches) were traced on this drapemeter. Each cardboard specimen was tested one by one on each drapemeter. Then the testing process was repeated for two measurements from each cardboard specimen. Cardboard circles were turned over for the second measurement. Drape shadow diagrams obtained from the two drapemeters were weighed and compared. Shadow diagrams from both drapemeters were compared to corresponding cardboard circles by laying cardboard circles on paper tracings.

Fifteen cardboard circular specimens with diameters ranging from 4 to 18 inches were placed face up then face down on the 4 inch circular platform having no edge curvature using the modified drapemeter. This platform was placed on pedestals of 5, 7, and 9 inches in height. All fifteen cardboard circles were tested twice at all three heights. The shadows of the projected cardboard circles were projected to the tracing shelf and traced. Then the traced shadow diagrams were cut out and weighed.

Research Hypothesis II: The modified drapemeter will replicate drape values obtained with the FRL drapemeter when using the same instrument parameters.

An additional comparison between the modified drapemeter and the FRL drapemeter was conducted using two medium-weight woven fabrics cut into 10 inch diameter circles. Fabrics were placed on a 4 inch circular platform with no edge curvature three times face up and three times face down. In the modified drapemeter the platform was supported by a pedestal which was 5 inch high. All projected drape shadows were traced, cut out and weighed.

Research Hypothesis III: The modified drapemeter will replicate drape values obtained with the FRL drapemeter when using three pedestal heights.

Two medium-weight woven fabrics were cut into 10 inch diameter circles. Fabrics were placed on a 4 inch circular platform with no edge curvature three times face up and three times face down for each pedestal height. In the modified drapemeter the platform was supported by pedestals of 5, 7, and 9 inches high. All projected drape shadows were traced, cut out, and weighed.

Research Hypothesis IV: Projected shadows obtained with the modified drapemeter will be have measurement repeatability.

The researcher conducted drape testing with a 10 inch diameter cardboard circle in the same laboratory on two different dates. The cardboard circle was measured three times face up and three times face down on a 4 inch diameter circular platform supported by pedestals 5, 7, and 9 inches high. A complete set of measurements was recorded each time the platform was supported by a different pedestal. Shadows of the cardboard circles were projected to the tracing shelf of the modified drapemeter, then traced. Paper tracings were cut out and weighed.

The researcher conducted drape testing with 10 inch diameter circles cut from two medium weight fabrics in the same laboratory on two different dates. The fabric circles were measured three times face up and three times face down on a 4 inch diameter circular platform supported by a pedestal 9 inches high. Shadows of the draped fabric circles were projected to the tracing shelf of the modified drapemeter, then traced. Paper tracings were cut out and weighed.

Dr. Carolyn Moore tested drape repeatability with a 10 inch diameter cardboard circle in the same laboratory on two different dates. The cardboard circle was measured three times face up and three times face down on a 4 inch diameter circular platform supported by pedestals 5, 7, and 9 inches high. A complete set of measurements was conducted each time the platform was supported by a different pedestal. Shadows of the cardboard circles were projected to the tracing shelf of the modified drapemeter, then traced. Paper tracings were cut out and weighed.

Jeanette Webb tested fabric drape repeatability with 10 inch diameter circles cut from two medium weight fabrics in the same laboratory on two different dates. The fabric circles were measured three times face up and three times face down on a 4 inch diameter circular platform supported by a pedestal 9 inches high. Shadows of the draped fabric circles were projected to the tracing shelf of the modified drapemeter, then traced. Paper tracings were cut out and weighed.

Research Hypothesis V: Length of fabric overhang from the 4 inch diameter platform disk with no edge curvature will influence node counts and drape values obtained from measurements of two medium weight woven fabrics.

The two medium weight fabrics were cut into circular specimens of 10, 14, and 18 inch diameters. These six fabric circles were draped one at a time over the circular platform with no edge curvature supported by the 9 inch pedestal. Drape shadows were traced, cut out, and weighed.

Research Hypothesis VI: The shape of the platform, oval versus round, will influence the node counts and drape values of two medium weight woven fabrics.

The two medium weight fabrics were cut into 10 and 18 inch diameter circles and 10 X 11 and 18 X 19 inch diameter ovals. Overhang lengths on both sets of specimens were held constant. Each specimen was draped three times face up and three times face down on a circular or oval platform. Circular specimens were draped over the circular platform, and oval specimens were drape over the oval platform. The oval shape (4 X 5 inches diameter) chosen for the platform was the resulting mean from waist measurements of five size 14 half-scale manikins. Both platforms used in the experiment had a ninety degree edge. The platforms were supported by a 9 inch high pedestal. Fabric drape shadows were traced, cut out, and weighed.

Research Hypothesis VII: The radius of curvature of the edge of the platform will influence node counts and drape values of two medium weight woven fabrics.

The two fabrics were cut to form six specimens each. Fabric specimens of 10 and 18 inch diameters were draped on a set of five 4 inch circular platforms. Oval fabric specimens of 10 X 11 and 18 X 19 inch diameters were draped on a set a set of five 4 X 5 inch oval platforms. Overhang length was held constant for all specimens. Oval specimens were cut with warp yarns parallel to both the long and short diameters. Each set of platforms have a different amount of edge curvature. The amount of edge curvature for each platform set varied in increments of 1/16 inch, ranging from 1/4 inch down to 0. Zero curvature indicates a 90 degree platform edge. Each of these platforms were supported by the 5 inch pedestal. Specimens were draped over each platform three times face up and three times face down at each pedestal height. Drape shadow diagrams were drawn for each test. Drape values were calculated for each test by the weight method.

Data Analysis

Statistical Hypothesis Ia. Mean weight differences between direct paper tracings of cardboard circles and paper tracings of projected shadows of cardboard circles obtained from the modified drapemeter and the FRL drapemeter are equal.

Independent Variables. Cardboard circles: Seven circular cardboard specimens with diameters ranging from 10.16 to 25.4 cm (4 to 10 inches) were each placed face up then face down on the platform so that their shadows could be projected to the tracing shelf.

Dependent Variables. Mean weight differences: Direct paper tracings of cardboard circles and paper tracings of projected shadows of cardboard circles were cut out then weighed.

Statistical Analysis. The paper tracings were analyzed statistically using paired t-tests to determine the accuracy of the modified drapemeter.

Statistical Hypothesis Ib. Mean weight differences between direct paper tracings of cardboard circles and paper tracings of projected shadows of cardboard circles obtained from the modified drapemeter using pedestal heights of 12.7 cm, 17.78 cm., and 22. 86 cm. (5, 7, and 9 inches) are equal.

Independent Variables. Cardboard circles: Fifteen circular cardboard specimens with diameters ranging from 10.16 to 45.72 cm (4 to 18 inches) were each placed face up then face down on the platform so that their shadows could be projected to the tracing shelf.

Pedestal heights: The fabric support platform was placed on pedestals of 12.7 cm, 17.78 cm., and 22. 86 cm. (5, 7 and 9 inches) in height.

Dependent Variables. Mean weight differences: Direct paper tracings of cardboard circles and paper tracings of projected shadows of cardboard circles were cut out then weighed.

Statistical Analysis. The paper tracings were analyzed statistically using ANOVA procedures to determine the accuracy of the modified drapemeter.

Statistical Hypothesis II. Mean drape values obtained for two medium weight fabrics using the modified drapemeter and the FRL drapemeter when using the same instrument parameters are equal.

Independent Variables. Fabric: Circular specimens with 25.4 cm (10 inch) diameters from two medium weight fabrics were place on the support platform three times face up and three times face down.

Dependent Variables. Drape values:

$$DV = \frac{AS - AP}{AF - AP} X\ 100$$

where AS = area of shadow; AP = area of platform; and AF = area of fabric specimen

Statistical Analysis. Obtained drape values were analyzed statistically using paired t-tests.

Statistical Hypothesis III. Mean drape values obtained for 25.4 cm (10 inch diameter) circular specimens of two medium weight fabrics with the modified drapemeter using pedestal heights of 12.7 cm, 17.78 cm, and 22.86 cm (5, 7, and 9 inches) are equal.

Independent Variables. Fabric: Circular specimens with 25.4 cm (10 inch) diameters from two medium weight fabrics were place on each support platform three times face up and three times face down.

Pedestal height: The fabric support platform was placed on pedestals of 12.7 cm, 17.78 cm, and 22.86 cm (5, 7 and 9 inches) in height.

Dependent Variables. Drape values:

$$DV = \frac{AS - AP}{AF - AP} X 100$$

where AS = area of shadow; AP = area of platform; and AF = area of fabric specimen

Statistical Analysis. Obtained drape values were analyzed statistically using ANOVA procedures.

Statistical Hypothesis IVa. Mean weight differences between direct paper tracings of cardboard circles and paper tracings of projected shadows of cardboard circles obtained from the modified drapemeter by the same operator in the same laboratory at two different dates are equal.

Independent Variables. Cardboard circles: A circular cardboard specimen with a 25.4 cm (10 inch) diameter was placed three times face up then three times face down on the platform so that the shadows could be projected to the tracing shelf.

Dependent Variables. Mean weight differences: Direct paper tracings of cardboard circles and paper tracings of projected shadows of cardboard circles were cut out then weighed.

Statistical Analysis. The paper tracings were analyzed statistically using a paired t-test to determine reliability for the modified drapemeter.

Statistical Hypothesis IVb. Mean drape values between direct paper tracings of cardboard circles and paper tracings of projected shadows of cardboard circles obtained from the modified drapemeter by the same operator in the same laboratory at two different dates are equal.

Independent Variables. Fabric: Circular specimens with 25.4 cm (10 inch) diameters from two medium weight fabrics were place on the support platform three times face up and three times face down.

Dependent Variables. Drape values:

$$DV = \frac{AS - AP}{AF - AP} X\ 100$$

where AS = area of shadow; AP = area of platform; and AF = area of fabric specimen

Statistical Analysis. Obtained drape values were analyzed statistically using a paired t-test to determine reliability for the modified drapemeter.

Statistical Hypothesis IVc. Mean drape values obtained from the modified drapemeter by two different operators in the same laboratory at two different dates are equal.

Independent Variables. Cardboard: A circular cardboard specimen with a 25.4 cm (10 inch) diameter was placed three times face up then three times face down on the platform so that the shadows could be projected to the tracing shelf.

Dependent Variables. Mean weight differences: Direct paper tracings of cardboard circles and paper tracings of projected shadows of cardboard circles were cut out then weighed.

Statistical Analysis. The paper tracings were analyzed statistically using a paired t-test to determine reliability for the modified drapemeter.

Statistical Hypothesis IVd. Mean drape diagram weight differences and drape values obtained from the modified drapemeter by two different operators in the same laboratory at two different dates are equal.

Independent Variables. Fabric: Circular specimens with 25.4 cm (10 inch) diameters from two medium weight fabrics were place on the support platform three times face up and three times face down.

Dependent Variables. Drape values:

$$DV = \frac{AS - AP}{AF - AP} X\ 100$$

where AS = area of shadow; AP = area of platform; and AF = area of fabric specimen

Statistical Analysis. Obtained drape values were analyzed statistically using a paired t-test to determine reliability for the modified drapemeter.

Statistical Hypothesis V. The length of fabric overhang from the 4 inch diameter platform disk with no edge curvature does not influence node counts and mean drape values obtained from measurements of two medium weight fabrics of 10, 14, and 18 inch diameters with 3, 5, and 7 inch overhang lengths respectively.

Independent Variables. Fabric: Circular specimens with 25.4 cm (10 inch), 35.56 cm (14 inch), and 45.72 cm (18 inch) diameters from two medium weight fabrics were placed on the support platform supported by a 22.86 cm (9 inch) high pedestal three times face up and three times face down.

Fabric overhang length: Fabric overhang lengths of 7.62, 12.7, and 17.78 cm (3, 5, and 7 inches) were obtained by draping specimens of different diameters over the same support platform of 10.16 cm (4 inches) in diameter.

Dependent Variables. Drape values:

$$DV = \frac{AS - AP}{AF - AP} X 100$$

where AS = area of shadow; AP = area of platform; AF = area of fabric specimen

Statistical Analysis. Obtained drape values were analyzed statistically using ANOVA procedures to determine reliability for the modified drapemeter. Node counts were reported as mean frequency counts.

Statistical Hypothesis VI. The shape of the platform, oval versus round, does not influence node counts and mean drape values of two medium weight fabrics.

Independent Variables. Fabric: Circular specimens with 25.4 cm (10 inch) and 45.72 cm (18 inch) diameters and oval specimens with 25.4 X 27.94 cm (10 X 11 inch) and 45.72 X 48.26 cm (18 X 19) inch diameters from two medium weight fabrics were placed on the support platform three times face up and three times face down.

Platform shape: Circular specimens were draped over a 10.16 cm (4 inch) diameter circular platform and oval specimens were draped over a 10.16 X 12.7 cm (4 X 5 inch) diameter oval platform.

Dependent Variables. Drape values:

$$DV = \frac{AS - AP}{AF - AP} X 100$$

where AS = area of shadow; AP = area of platform; and AF = area of fabric specimen

Statistical Analysis. Obtained drape values were analyzed statistically using ANOVA procedures to determine reliability for the modified drapemeter.

Statistical Hypothesis VII. The radius of curvature of the edge of the platform does not influence node counts and mean drape values of two medium-weight woven fabrics.

Independent Variables. Fabric: Circular specimens with 25.4 cm (10 inch) and 45.72 cm (18 inch) diameters and oval specimens with 25.4 X 27.94 cm (10 X 11 inch) and 45.72 X 48.26 cm (18 X 19) inch diameters from two medium weight fabrics were placed on the support platform three times face up and three times face down.

Platform edge curvature: Platform edges ranged in curvature by 0 to 1.27 cm (1/2 inch) radii in 0.16 cm (1/16 inch) increments.

Dependent Variables. Drape values:

$$DV = \frac{AS - AP}{AF - AP} X 100$$

where AS = area of shadow; AP = area of platform; and AF = area of fabric specimen

Statistical Analysis. Obtained drape values were analyzed statistically using ANOVA procedures to determine reliability for the modified drapemeter.

CHAPTER 5: RESULTS AND CONCLUSIONS

Results

Drape testing was conducted entirely by the researcher except in the cases of those trials conducted by other operators in order to establish within-laboratory reliability. The researcher traced all drape diagrams of the fabric shadows and then cut diagrams along the outside edge of the tracing line. Since shadow areas were determined by weight measurement, any difference in cutting method could significantly affect the obtained weights used to calculate drape coefficients and drape values.

All statistical analyses were conducted with version 5.03 Number Cruncher Statistical System (NCSS) software and a personal computer. The paired t-test and various analysis of variances (ANOVA) used were processed as model versions of the general linear models analysis of variance/covariance program. Drape coefficients and drape values were transformed for data processing in ANOVA models but were converted back to drape coefficients and values for reporting of results. Scheffe's procedure and Fisher's LSD tests were conducted as post hoc means for further analyzing significant results obtained with ANOVA. Descriptive statistics procedures were used to numerically summarize variables and obtain means and standard deviations. Graphs were generated by Key Cad Complete software for producing precision engineering designs.

Statistical Hypothesis I

Statistical Hypothesis Ia: Mean drape diagram weight differences and drape values obtained from the modified drapemeter and the FRL drapemeter are equal.

Hypothesis Ia was concerned with comparing the equivalence of the FRL drapemeter and the modified drapemeter. Accuracy of the modified drapemeter was inferred by comparing it with the FRL drapemeter which traditionally has a high level of acceptance for accuracy for measuring fabric drape. Data were collected for Hypothesis Ia in the form of weight differences by weighing tracings of projected shadows of cardboard circles. Cardboard circles with diameters ranging from 4 to 10 inches were traced on paper. Then the circles were cut along the interior edge of the traced line. The weight of the paper circles (which were the same diameter as the cardboard circles) was subtracted from the weight of the paper cutting obtained by tracing the projected shadow of the cardboard circles. The weight differences obtained with the FRL drapemeter were compared to weight differences obtained with the modified drapemeter with a paired t-test. (For hypothesis I all paired t-tests were conducted by an equivalent ANOVA procedure in NCSS.) There was no evidence (p = .767) of significant difference in results obtained by both drapemeters, thus null Hypothesis Ia was accepted (Table 2).

Table 2. Comparison of Accuracy of FRL Drapemeter With Modified Drapemeter Using Cardboard Specimens

VARIABLE	DF	MEAN DIFFERENCE	F-RATIO	OBSERVED P-VAIUE
Drapemeter	1	.023305 g	0.09	P = .7670

Specimens of 10 inch diameters were cut from two medium weight woven fabrics. They were draped on 4 inch circular platforms with 90 degree edges supported by 5 inch high pedestals on both the FRL and the modified drapemeters. Paper tracings of draped fabric shadows were cut out and weighed. Node counts were recorded and averaged. The mean node count for drape diagrams obtained from the FRL drapemeter was 4.1. The average number of nodes on the drape diagrams obtained with the modified drapemeter was 3.85. Drape coefficients calculated from drape diagrams obtained from both drapemeters were also compared by an analysis of variance (ANOVA) using a two factor (fabric and drapemeter) factorial model. Because drape coefficients were small percent values, they were transformed to radians by the arcsine and square root transformation. Transformed drape coefficients served as the y-value in the ANOVA model. No significant interaction ($p < .9226$) was found between the fabric and drapemeter factors (Table 3). Comparison results obtained with fabric specimens were consistent with results obtained with cardboard samples, thus it was concluded that the modified drapemeter was as accurate as the FRL drapemeter. Again hypothesis Ia was accepted.

Table 3. Comparison of FRL Drapemeter and Modified Drapemeter Using Two Medium Weight Fabric Specimens

VARIABLE	DF	MEAN DRAPE COEFFICIENT	F-RATIO	OBSERVED P-VAIUE
Drapemeter	1	36.73%	0.01	$P = .9226$

Statistical Hypothesis Ib: Mean drape diagram weight differences obtained from the modified drapemeter using pedestal heights of 5, 7, and 9 inches are equal.

Another test was conducted to determine the accuracy of the modified drapemeter. Data were collected for Hypothesis Ib in the form of weight differences between paper circles and drape diagrams of cardboard circles. These data were used as the y-value as Hypothesis Ib was tested by using an analysis of variance with a two factor (cardboard diameter and pedestal height) factorial model. The two-factor interaction was used to determine if the pedestal height made a difference in the area of the projected drape diagram. Cardboard specimens with diameters ranging from 4 to 18 inches were placed on circular platforms supported by pedestals of three heights. Diameters of cardboard circles were significantly different ($p <$ .0001) since they were cut with the diameters increasing by 1 inch increments (ranging from 4 to 18 inch diameters). There was no significant difference due to pedestal height; but a significant interaction, $p = .0286$, was found between pedestal height and cardboard diameters (Table 4).

Table 4. ANOVA of Interactions Between Weight Differences of Cardboard Tracings, Cardboard Diameters, and Pedestal Heights

VARIABLE	DF	MEAN DIFFERENCE	F-RATIO	OBSERVED P-VAIUE
Cardboard Diameter	14	0.04917 g	9.05	$P = .0001$
Pedestal Height	2	0.04917 g	0.76	$P = .4746$
Interaction	28	0.04917 g	1.88	$P = .0286$

Weight differences among specimen diameters were found to be significant ($p < .0001$). The p-value for testing weight differences between pedestal heights was .4746, which means pedestal heights do not significantly affect the accuracy of the drape diagrams obtained with the modified drapemeter. Since accuracy testing concerned the pedestal height factor, hypothesis Ib was accepted.

Effects of human error in tracing and cutting the projected shadow diagrams of the cardboard circles logically would increase with the increase in diameter of the cardboard circles. The possible increase in human error that could correspond with increased cardboard circle diameters might account for some of the significant differences found in the interaction between weight differences of cardboard circle tracings and cardboard circle diameters. Results indicated interaction between the factors as indicated by the nonparallel mean profile plots and statistical tests. Figure 4 (graph) is a representation of how the drape value means respond inconsistently for all factor levels.

Comparison of mean differences and standard deviations for each pedestal height are found in Table 5.

Table 5. Accuracy Comparison by Pedestal Heights

PEDESTAl HEIGHT	MEAN DIFFERENCE	STANDARD DEVIATION
5 Inches	0.0230750 g	0.01068855
7 Inches	0.0175125 g	0.00811831
9 Inches	0.0134875 g	0.01031427

Mean differences decreased as the pedestal height increased. Thus, arguments for increasing the pedestal height in order to measure larger fabric specimens were supported by findings (mean differences between weight differences of cardboard circle tracings) that increased pedestal heights also increased accuracy. However, standard deviations indicated that measurements were more precise with the 7 inch high pedestal. Based on these findings of accuracy, it was determined that for the rest of this study all fabric specimens were to be measured at the 9 inch pedestal height.

Statistical Hypothesis Ic: Mean drape diagram weight differences and drape values obtained from the modified drapemeter by the same operator in the same laboratory at two different dates are equal.

In order to establish reliability the researcher conducted drape testing with 4 to 18 inch diameter cardboard specimens in the same laboratory on two different dates. The cardboard circles were measured face-up and face-down on a circular platform supported by pedestals 5, 7, and 9 inches high. Differences in weights of paper tracings of projected shadows of

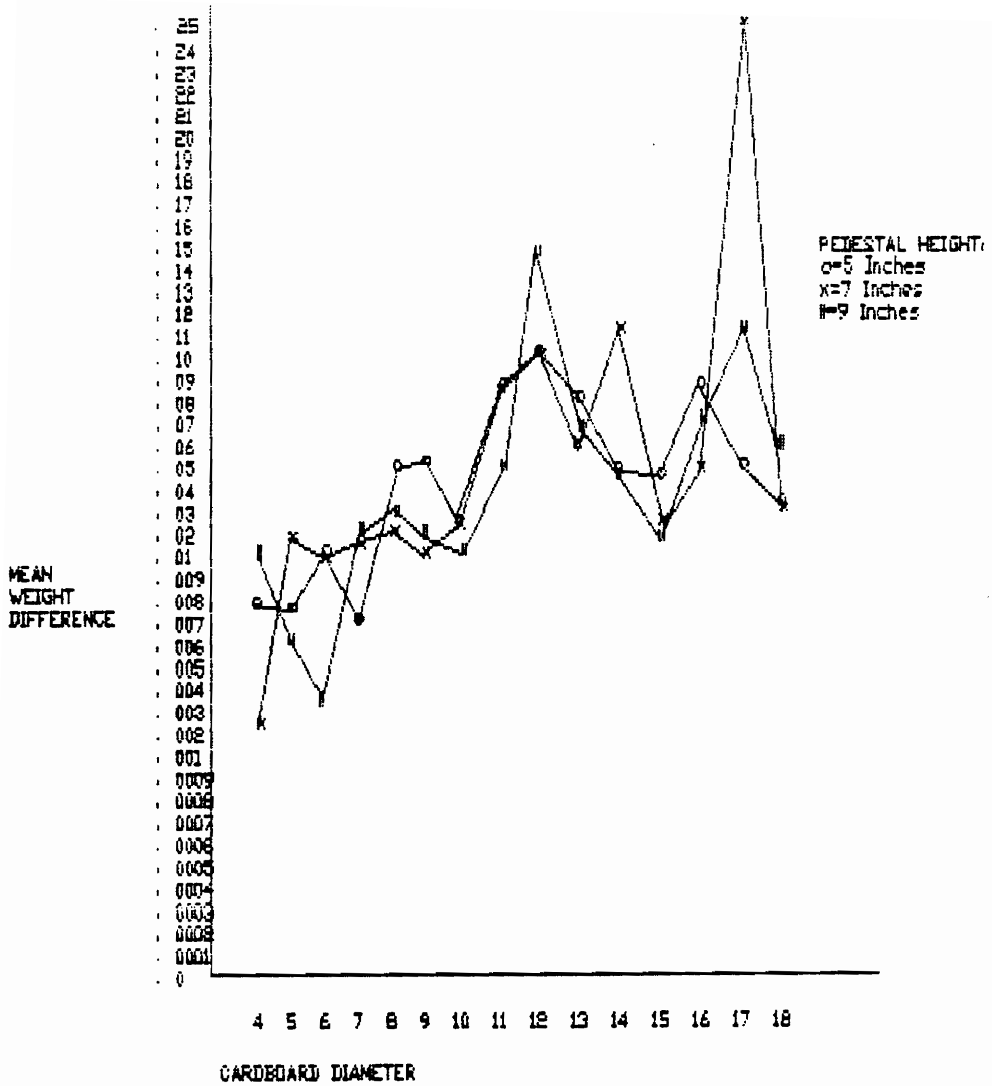

Figure 4. Interaction Between Weight Differences of Cardboard Tracing, Cardboard Diameters, and Pedestal Heights

cardboard circles and paper circles drawn the same diameter of the cardboard were summarized by descriptive statistics. The standard deviation between results was found to be 0.0401 g. A distribution of mean differences comparing cardboard circle tracings with shadow tracings indicated that accuracy was very high for all cardboard diameters except those of 12, 13, 16, and 17 inches (Table 6). A paired T-test was conducted comparing the differences obtained in the two trials. A P-value of .125 indicated that there were no significant differences in drape measurements obtained when the same operator measured drape with the modified drapemeter on two different dates (Table 7).

Table 6. Distribution of Differences Comparing Cardboard Circle Tracings to Shadow Tracings Mean Difference

Cardboard Diameter	Top	Bottom
4 inch	0.012750 g	0.014750 g
5 inch	0.006299 g	0.004600 g
6 inch	0.003499 g	0.003950 g
7 inch	0.022400 g	0.019750 g
8 inch	0.029350 g	0.025250 g
9 inch	0.018850 g	0.011050 g
10 inch	0.013300 g	0.012400 g
11 inch	0.051150 g	0.037300 g
12 inch	0.146350 g	0.128100 g
13 inch	0.067350 g	0.044950 g
14 inch	0.049250 g	0.023800 g
15 inch	0.017300 g	0.046750 g
16 inch	0.072400 g	0.108550 g
17 inch	0.113800 g	0.073500 g
18 inch	0.058840 g	0.002289 g

Table 7. Differences in Cardboard Tracings (Reliability for Single-Operator-Between Times)

VARIABLE	DF	MEAN DIFFERENCE	F-RATIO	OBSERVED P-VAlUE
Trial	1	0.04201 g	2.45	P = .1250

Another test for establishing single-operator-between-times reliability was conducted by the researcher with two medium weight fabric specimens, 10 inches in diameter. The fabric circles were measured face-up and face-down on a circular platform supported by a pedestal 9 inches high. Drape values from both trials were compared using a paired T-test. A P-value of .7269 indicated that there was no significant difference in drape measurements obtained when the same operator measured fabric drape with the modified drapemeter on two different dates (Table 8). Hypothesis Ic was accepted.

Table 8. Drape Values for Two Medium Weight Fabrics (Reliability for Single-Operator-Between Times)

VARIABLE	DF	MEAN DRAPE COEFFICIENT	F-RATIO	OBSERVED P-VAlUE
Trial	1	44.11583%	0.13	P = .7269

Statistical Hypothesis Id: Mean drape diagram weight differences and drape values obtained from the modified drapemeter by two different operators in the same laboratory at two different dates are equal.

Two tests of reliability were conducted by two different operators in the same laboratory on two different dates. The first test utilized cardboard specimens. Dr Carolyn Moore and the researcher were the two operators. Differences in paper tracings obtained from 10 inch diameter cardboard specimens at three pedestal heights were summarized with descriptive statistics. The standard deviation of results for this operator was found to be 0.0094. The standard deviation for the researcher was 0.0115. Standard deviations between the two operators was 0.0102. A paired T-test (p = .3664) indicated no significant difference in results when two operators measured drape with the modified drapemeter on two different dates (Table 9). Since the second operator and the researcher produced consistent results, it was concluded that differences in cardboard tracings obtained with the modified drapemeter demonstrated within-laboratory reliability.

Table 9. Differences in Cardboard Tracings (Within-Laboratory Reliability)

VARIABLE	DF	MEAN DIFFERENCE	F-RATIO	OBSERVED P-VAlUE
Operator	1	0.018025 g	0.85	P = .3664

The second test utilized two medium weight woven fabric specimens. Jeanette Webb and the researcher were the two operators. Drape values were obtained from shadow diagrams of 10 inch diameter fabric specimens placed over a circular platform supported by a 9 inch high pedestal. Descriptive statistics were used to summarize the drape values. The standard deviation for Jeanette was found to be 0.02219. The standard deviation for the researcher was found to be 0.02824. The standard deviation between the two operators was 0.02552. An ANOVA (p = .2212) indicated non-significant differences when two different operators measured fabric drape with the modified drapemeter on two different dates (Table 10). The second operator and the researcher produced similar drape value means. Hypothesis Id was accepted.

Table 10. Drape Values for Two Medium Weight Fabrics (Within-Laboratory Reliability)

VARIABLE	DF	MEAN DRAPE VAlUES	F-RATIO	OBSERVED P-VAlUE
Operator	1	43.6774%	1.54	P = .2212

Statistical Hypothesis II: The length of fabric overhang from the 4 inch diameter circular platform disk with no edge curvature does not influence node counts and mean drape values obtained from measurements of two medium weight fabrics of 10, 14, and 18 inch diameters with 3, 5, and 7 inch overhang lengths respectively.

To test the effect of fabric overhang length on node counts and drape values, two medium weight woven fabrics were draped over a circular platform (4 inch diameter) supported by a pedestal 9 inches high. Both fabrics were cut into three circles with diameters of 10, 14, and 18 inches which produced overhang lengths of 3, 5, and 7 inches respectively. Drape diagrams increased in node formation and node length as fabric overhang length increased. Mean node counts were 4.5, 4.8, and 5 respectively for 10, 14, and 18 inch diameter specimens of 100% cotton. Mean node counts were 3.8, 4.2, and 4.7 respectively for 10, 14, and 18 inch diameter specimens of polyester/wool. Table 11 reports node trends.

Table 11. Node Counts Due to Specimen Drape Overhang Length

DRAPE OVERHANG LENGTH	MEAN NODE COUNT FOR 100% COTTON FABRIC	MEAN NODE COUNT FOR POLYESTER/WOOL FABRIC
3 inches	4.2	3.8
5 inches	4.3	4.0
7 inches	4.5	4.7

Table 12 reports mean drape values for two medium weight woven fabric specimens cut in three diameters. Drape values decreased as specimen diameter (thus, drape overhang length) increased.

Table 12. Drape Values Due to Specimen Drape Overhang Length.

DRAPE OVERHANG LENGTH	MEAN DRAPE VAIUES FOR 100% COTTON FABRIC	MEAN DRAPE VAIUES FOR POLYESTER/WOOL FABRIC
3 inches	43.23%	44.37%
5 inches	18.25%	24.16%
7 inches	12.20%	15.71%

Transformed drape values were compared with fabric type and specimen diameter in a two-factor factorial ANOVA. Because NCSS has difficulty in accurately processing small percentages in ANOVA procedures, drape values were transformed to radians by the arcsine and square root transformation. Actual drape value means were reported in tables (Table 13).

Table 13. Drape Values for Two Medium Weight Fabrics Measured in Three Drape Overhang Lengths

VARIABLE	DF	MEAN DRAPE VAlUES	F-RATIO	OBSERVED P-VAlUE
Drape Overhang Length	2	26.44608%	594.05	P=0.0001

Results indicated that fabric had no significant effect on drape values. Since fabrics were chosen to have similar characteristics, a significant affect was not expected. Specimen diameter affecting drape overhang lengths were found to have a highly significant (p < .0001) influence on drape value. Thus, Hypothesis II was rejected.

Because significant differences were found in drape values due to changes in drape overhang length, Scheffe's procedure and Fisher's LSD test were conducted (alpha level = 0.01). Scheffe's procedure was recommended because it can determine very large differences between comparisons when the factor's F-test is significant. Fisher's LSD test compares all possible pairs of means. Results were the same for both procedures (Table 14). Drape values were found to be significantly different for all three drape overhang lengths, 3, 5, and 7 inches. The "S" indicated that the mean drape value for a particular drape overhang length was significantly different from mean drape values calculated from drape diagrams traced at other pedestal heights. Mean drape values were found to be significantly different at all drape overhang lengths.

Table 14. Fisher's LSD Comparison Report.

Drape Overhang Length	Drape Overhang Length in Inches			Mean Drape Values
	3	5	7	
3 Inches		S	S	44.02657%
5 Inches	S		S	19.83167%
7 Inches	S	S		14.80000%

Statistical Hypothesis III: The shape of the platform, oval versus round, does not influence node counts and mean drape values of two medium weight fabrics of two overhang lengths.

To test the effect of platform shape on node counts and drape values, two medium weight woven fabrics were cut into circular and oval specimens. Circular fabric specimens were draped over a circular platform (4 inch diameter) supported by a pedestal 9 inches high. Both fabrics were cut into two circles with diameters of 10 and 18 inches to produce 3 and 7 inch overhang lengths respectively. Oval fabric specimens were draped over an oval platform (4 X 5 inch diameter) supported by a pedestal 9 inch high. Both fabrics were cut into four ovals, two with diameters of 10 X 11 inches and two with diameters of 18 X 19 inches to produce overhang lengths of 3 and 7 inches respectively. Each specimen in a set of oval fabrics was distinguished by warp yarn direction.

Drape diagrams obtained from the oval platform had a larger area as indicated by paper weight than drape diagrams obtained from the round platform. The drape value did not reflect the difference in drape diagram shape since the formula subtracts oval shapes for oval specimens and circular shapes for circular specimens. Mean node counts had an inconsistent tendency to increase with oval shapes. Both oval and circular specimens showed a trend for increased node count and node length with increased drape overhang length.

Transformed drape values were analyzed in a three-factor factorial ANOVA. The three factors were fabric, drape overhang length (specimen diameter), and platform shape. Fabric did not have any significant influence ($p < .9832$) on drape value. Specimen overhang length was a highly significant influence ($p < .0001$) on drape value. Platform shape was also a highly significant influence ($p < .0001$) on drape value. There also was a significant interaction ($p < .0130$) between the influence of fabric and platform shape on the drape value. Direction of the warp yarns in the oval specimens may have attributed to this interaction. There was no significant interaction ($p = .0886$) between fabric and overhang length or shape and overhang length. An overall P-value of .0732 for the three-factor interaction of fabric, drape overhang length, and platform shape as an influence on the drape value was probably due to the insignificant influence ($p = .9832$) of the fabric factor (Table 15). In general practice Hypothesis III would be accepted because the MANOVA was significant. Since the influence of the platform disk shape on dependant variables was the focus of this hypothesis, the summary of influences attributed to the platform disk shape factor was isolated. The very significant influence of the platform shape factor indicated cause for rejection of this hypothesis.

Statistical Hypothesis IV: The radius of curvature of the edge of the platform does not influence node counts and mean drape values of two medium-weight woven fabrics.

To test the effect of platform edge curvature radii on node counts and drape values, two medium weight woven fabrics were cut into circular and oval specimens. The 4 inch diameter circular and the 4 X 5 inch diameter oval platforms had radii ranging from 0/16 to 4/16 in

Table 15. Drape Values for Two Medium Weight Fabrics Measured on Two Platform Shapes

VARIABLE	DF	MEAN DRAPE VALUES	F-RATIO	OBSERVED P-VALUE
Fabric	1	28.814585%	0.00	$\underline{P}$ = .9832
Drape Overhang Length	1	28.814585%	312.70	$\underline{P}$ = .0001
Fabric & Drape Overhang Length Interaction	1	28.814585%	2.99	$\underline{P}$ = .0886
Platform Shape	1	28.8145875%	18.84	$\underline{P}$ = .0001
Fabric & Platform Shape Interaction	1	22.8145875%	6.53	$\underline{P}$ = .0130
Drape Overhang Length & Platform Shape Interaction	1	28.8145850%	0.10	$\underline{P}$ = .7498
Interaction of All Variables	1	28.1458370%	3.32	$\underline{P}$ = .0732

increment differences of 1/16 inch. Circular fabric specimens were draped over each of the five circular platforms supported by a pedestal 9 inches high. Both fabrics were cut into two circles with diameters of 10 and 18 inches to produce overhang lengths of 3 and 7 inches respectively. Oval fabric specimens were draped over each of the five oval platforms supported by a pedestal 9 inches high. Both fabrics were cut into four ovals, two with diameters of 10 X 11 inches and two with diameters of 18 X 19 inches to produce overhang lengths of 3 and 7 inches respectively. Each specimen in a set of oval fabrics was distinguished by warp yarn direction.

Drape diagrams were not different due to draping specimens over platforms with edges of varied radii. Mean node counts indicated no consistent trends due to platform edge radii.

Transformed drape values were analyzed in a four-factor factorial ANOVA. The four factors were fabric, drape overhang length, platform shape, and platform edge radii. Fabric did not have any significant influence ($p = .1343$) on drape value (Table 16). The interaction of drape overhang length and platform shape were found to contribute an insignificant influence ($p = .1265$) on drape value. Change in platform edge curvature radii attributed a significant influence ($p < .0416$) of drape values.

Table 16. Drape Values for Two Medium Weight Fabrics Measured on Platforms with Five Different Edge Curvature Radii

VARIABLE	DF	MEAN DRAPE VAIUES	F-RATIO	OBSERVED P-VAIUE
Fabric	1	28.289105%	2.24	P=0.1343
Drape Overhang Length	1	28.289105%	14138.71	P=0.0001
Fabric & Drape Overhang Length Interaction	1	28.289105%	11.67	P=0.0006
Platform Shape	1	28.289104%	28.77	P=0.0001
Fabric & Platform Shape Interaction	1	28.289105%	1.00	P=0.3181
Drape Overhang Length & Platform Shape Interaction	1	28.2891925%	2.33	P=0.1265
Fabric, Drape Overhang Length, & Platform Shape Interaction	1	28.289105%	1.72	P=0.1892
Platform Edge Radii	4	28.289103%	2.51	P=0.0416
Fabric & Platform Edge Radii Interaction	4	28.288203%	0.65	P=0.6292
Drape Overhang Length & Platform Edge Radii Interaction	4	28.289104%	2.54	P=0.0398
Fabric, Drape Overhang Length, & Platform Edge Radii Interaction	4	28.2891037%	0.22	P=0.9267
Platform Shape & Edge Radii Interaction	4	28.289104%	2.96	P=0.0200
Fabric, Platform Shape, & Edge Radii Interaction	4	28.289105%	4.57	P=0.0013
Drape Overhang Length, Platform Shape, & Edge Radii Interaction	4	28.289104%	0.90	P=0.4649
Interaction of All Variables	4	28.289104%	7.09	P=0.0001

There was no significant influence ($p = .6292$) on drape values caused by interactions between fabric and platform edge radii. A significant influence ($p < .0398$) on drape values was indicated by interaction between fabric overhang length and platform edge radii. There also was a significant influence on drape value attributed to interaction between platform shape and platform edge radii ($p < .0200$). There were very strong influences on drape values attributed to interactions from fabric, platform shape, and platform edge curvature radii ($p < .0013$). Drape overhang length, platform shape, and platform edge radii created no significant ($p = .4649$) interaction influences on drape values. Since all four factors were interacting significantly ($p < .0001$) to influence the drape values, levels of all four factors must be taken into account to describe the drape value in this type of experimental set-up (Table 16). No consistent patterns could be attributed to the combination of all four factor levels because of the significant four factor interaction (Figure 5). Hypothesis IV was rejected.

Because significant differences were found in drape values due to changes in platform edge radii, Fisher's LSD test was conducted at both alpha level = 0.05 and alpha level = 0.01. Fisher's LSD test compares all possible pairs of means. Results for both procedures are reported in Tables 17 and 18. The "S" indicated that the mean drape value for a particular platform edge radii was significantly different from mean drape values calculated from drape diagrams traced with other platform edge radii.

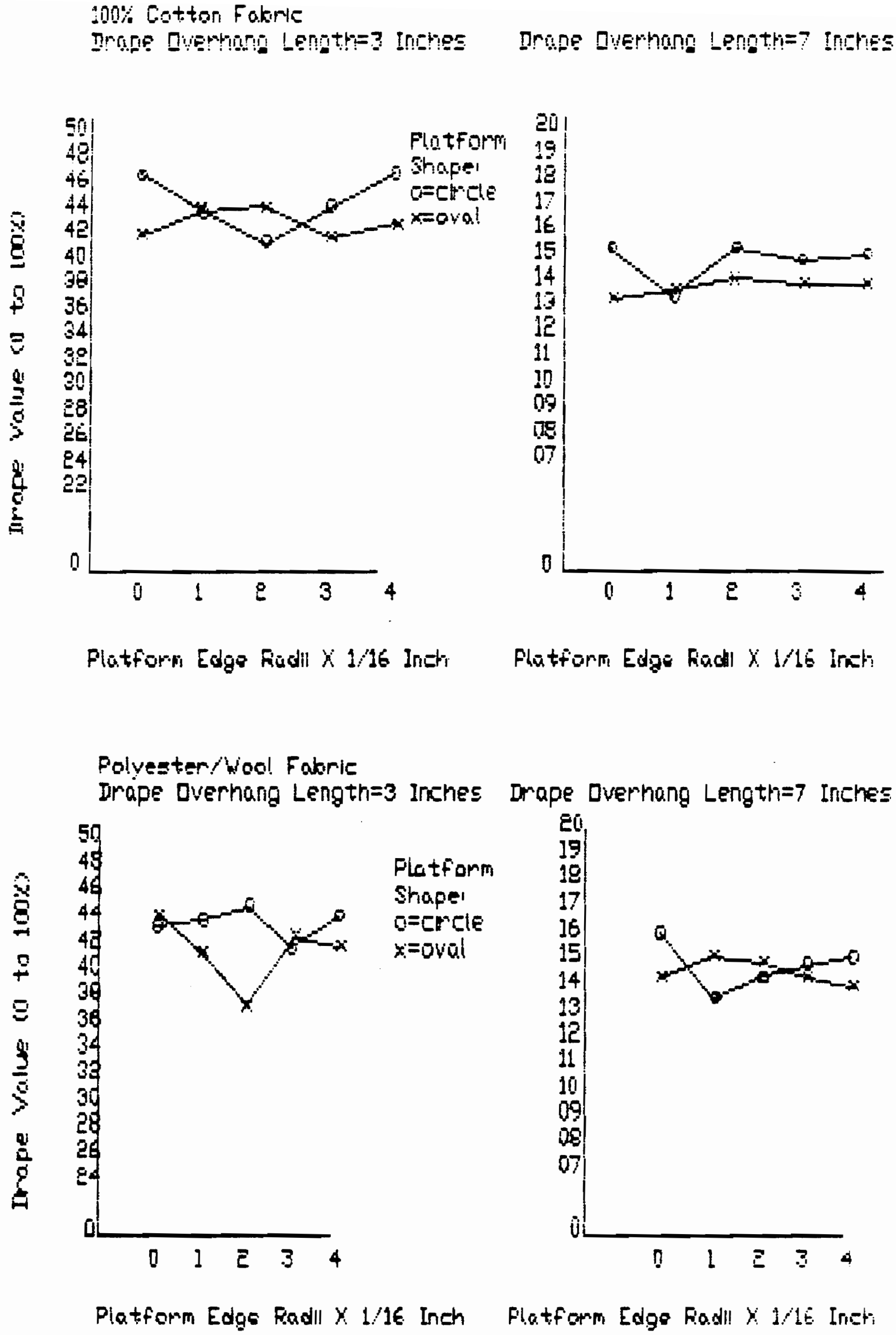

Figure 5. Interaction between Drape Values, Fabrics, Drape Overhang Length, and Platform Shape and Edge Radii.

Table 17. Fisher's LSD Comparison Report (Alpha Level=0.05)

		Platform Edge Radii				
Platform Edge Radii	Mean Drape Value	0/16	1/16	2/16	3/16	4/16
0/16 Inch	28.81458%		S	S		
1/16 Inch	28.01365%	S				
2/16 Inch	27.70844%	S				S
3/16 Inch	28.23340%					
4/16 Inch	28.67545%			S		

Table 18. Fisher's LSD Comparison Report (Alpha Level=0.01)

		Platform Edge Radii				
Platform Edge Radii	Mean Drape Value	0/16	1/16	2/16	3/16	4/16
0/16 Inch	28.81458%			S		
1/16 Inch	28.01365%					
2/16 Inch	27.70844%	S				
3/16 Inch	28.23340%					
4/16 Inch	28.67545%					

Conclusions

Statistical Hypothesis I

When evaluating the modified drapemeter by Cary and Sproles' (1978) framework, it was found to have utility. Utility of the modified drapemeter was determined partially by testing Hypothesis I. The concept of utility is relatively abstract. Utility can be measured by four identifiable factors: validity or accuracy, reliability, manageability, and essentiality (Cary

& Sproles, 1978). Parts "a" and "b" of Hypothesis I measured validity or accuracy. Parts "c" and "d" of Hypothesis I measured reliability. Manageability and essentiality were determined by personal interviews with persons who used the modified drapemeter for testing cardboard and fabric specimens.

Manageability is determined by the amount of resources which must be organized and controlled in order to test a product with an instrument. Instrument manageability is tested by face manageability, dependability, cost, and simplicity (Cary & Sproles, 1978). All operators who used the modified drapemeter found it an acceptable and dependable means for measuring fabric drape. The cost to build the modified drapemeter including all of its interchangeable parts was less than the cost to purchase the FRL drapemeter. Operation costs included tracing paper, pencil, and specimens. Thus, operation costs are identical to those needed to use the FRL drapemeter. It was simple to use the modified drapemeter, since it functions in the same manner as the FRL drapemeter. The parts were exchanged by removing and replacing a screw with an hex wrench or by hand. All parts were securely anchored by common, replaceable screws. Because the modified drapemeter is taller than the FRL drapemeter, a small aluminum step ladder was needed to facilitate drape diagram tracing. A set of wooden stairs could be permanently attached to one side of the modified drapemeter to eliminate need for a step ladder. Time to conduct one fabric drape test was slightly longer than time needed to use the FRL drapemeter. The required extra time was due to the need to open and close the door each time the specimen was changed. The modified drapemeter meets criteria for manageability.

Essentiality is determined by the need for the testing instrument and the ability for the instrument to measure fabric in a manner relevant to end use. Instrument essentiality is judged by face essentiality, interpretability, versatility, and priority (Cary & Sproles, 1978). Since the FRL drapemeter meets all criteria for essentiality, the modified drapemeter also meets this criteria. The modified drapemeter was found to be more versatile than the FRL drapemeter.

Statistical Hypothesis Ia: Mean drape diagram weight differences and drape values obtained from the modified drapemeter and the FRL drapemeter are equal.

The modified drapemeter was found to produce results as accurate as the FRL drapemeter. Accuracy was tested with both cardboard and fabric specimens. No significant difference was found between results obtained by the two drapemeters. Thus, it was demonstrated that the modified drapemeter accurately measures test fabric drape. It could also be concluded that it was possible to build a larger drapemeter that could hold larger fabric specimens and still get accurately projected drape diagram shadows. A comparison of differences between traced cardboard circles and traced shadows found that accuracy improved as the pedestal height increased.

Since the cardboard shadow tracings differ from cardboard tracings in an inconsistent manner among diameter changes, there was a strong indication of human error in both cutting the cardboard and tracing and cutting of the paper circles. A photographic or video system may help eliminate differences due to human error. Using a planimeter would control some error by eliminating the need for cutting and weighing paper. The nature of corrugated cardboard also contributed to the differences in the cardboard tracings and the shadow tracings. The cardboard circles with 12, 14, 16, and 17 inch diameters (especially the 12 inch diameter circle) had many more protrusions than the other cardboard circles. These same circles contributed to shadow tracings that indicated the most difference. The protrusions varied with time on all the cardboard circles, thus causing differences in tracings with time due to protrusion variability. Heavy weight tag board is recommended for future comparison studies in order to eliminate the differences caused by corrugated cardboard protrusions.

Statistical Hypothesis Ib: Mean drape diagram weight differences obtained from the modified drapemeter using pedestal heights of 5, 7, and 9 inches are equal.

Accuracy of measuring fabric drape at the three different pedestal heights was found to be accepted. Hypothesis Ib "was accepted" even though overall significance was found to be $p < .0286$. Normally an observed significance level p-value less than 0.05 indicates a hypothesis should be rejected, but in this case significance of interaction between measurements of cardboard circles and pedestal heights is not of prime importance. Accuracy of drape measurement due to changes in height of pedestals was the prime concern in testing Hypothesis Ib.

Since changes in cardboard diameters probably greatly affected the overall interaction (Cardboard circles developed protrusions.), the resultant overall p-value likely does not reveal actual differences caused by changes in pedestal heights. The overall significant interaction more likely indicates differences caused by human error. Since diameters of paper tracings of both drape shadows and cardboard circumferences should have been the same, significant weight differences involving cardboard diameters could be attributed to human error. Human error could occur during cardboard circumference tracing and cutting or during shadow tracing and cutting.

A comparison of accuracy at each pedestal height revealed that accuracy actually improved as pedestal height increased. Since the FRL drapemeter has a permanent drape support system of five inches in height, it could be concluded that the 9 inch high pedestal improved drape measurement as well as accommodated larger specimens.

Statistical Hypothesis Ic: Mean drape diagram weight differences and drape values obtained from the modified drapemeter by the same operator in the same laboratory at two different dates are equal.

The modified drapemeter was found to be a reliable means for testing fabric drape. Reliability is the tendency to provide consistent results for identical objects (Cary & Sproles, 1978). Rejected Hypothesis Ic measured single-operator-between-times reliability. Thus, the modified drapemeter was found to be a reliable means for measuring drape when the same operator conducted the same experiments on two different dates.

Statistical Hypothesis Id: Mean drape diagram weight differences obtained from the modified drapemeter by two different operators in the same laboratory at two different dates are equal.

Rejected Hypothesis Id measured within-laboratory reliability. The modified drapemeter was found to be a reliable means for measuring drape when different operators conducted the same experiments on two different dates in the same laboratory. Reliable results were obtained with comparisons of cardboard shadow diagram weight differences and with comparisons of mean drape values from fabric drape testing. It was concluded that undisputed results obtained with the modified drapemeter were consistent and reliable. Thus, the modified drapemeter was found to be a reliable means for measuring drape when different operators conducted the same experiments on two different dates.

Statistical Hypothesis II: The length of fabric overhang from the 4 inch diameter circular platform disk with no edge curvature does not influence node counts and mean drape values obtained from measurements of two medium weight fabric specimens of 10, 14, and 18 inch diameters.

Since all circular specimens were draped over a circular platform of the same diameter, increase in specimen diameter indicated an increase in specimen overhang length from 3, to 5, and to 7 inches. Specimen diameter change (overhang length) was found to influence drape diagrams, node counts and drape values. Thus change in drape overhang length indicated a highly significant influence in drape values.

A significant interaction between the fabric and platform shape factors (tested as factors in Hypotheses III and IV) indicated that the mean drape values for the two fabrics were inconsistent for the two shapes. Larger oval specimens draped over oval platforms were found to have lesser mean drape values than when larger round specimens were draped over round platforms. The polyester/wool fabric was found to have lesser mean drape values than the 100% cotton fabrics when draped as oval specimens over oval platforms. Linear inconsistencies were found with interactions between 100% cotton fabrics cut into smaller circular specimen shapes and draped over circular platforms.

Gravity had a greater influence with drape values as the fabric overhang length was increased. All objects attract each other. The force of their attraction depends on the sizes of the objects and the distance between them. The force of attraction is in direct proportion to the product of an object's mass. The larger the mass, the greater the attraction. Gravitational force is also in inverse proportion to the square of the distance between the centers of mass of the attracted objects. The farther apart the objects are, the less the gravitational force (Hewitt, 1989). The greater the area of a specimen, the greater was the gravitational pull. The specimens with the larger diameters were subjected to greater gravitational pull; thus, the larger specimens fell in more vertical patterns resulting in smaller drape values. When fabric specimens fall closer to an area as would happen when they fall in a more vertical pattern, the excess fabric in the outer edge would buckle into deep double folds in order to gather closer to that area. Increased node length and counts corresponding to increased specimen diameter supported this conclusion.

Both Scheffe's procedure and Fisher's LSD test revealed significant differences due to each comparison of drape overhang lengths. Thus, 3 inch overhang lengths (10 inch diameters) were significantly different from both 5 (14 inch diameter) and 7 inch (18 inch diameters) overhang lengths. Five inch overhang lengths were significantly different from 3 and 7 inch overhangs. And 7 inch overhangs were significantly different from 3 and 5 inch overhangs.

The significant relationship between drape overhang length and drape value indicated a need to conduct measurements with larger specimen dimensions since most apparel parts are larger than 10 inches in diameter. A justification for drape testing was to gain an understanding of how a particular fabric would behave if it became part of a garment. However, a minimized difference in drape values between fabrics occurs when specimens with longer overhang lengths are measured. Thus, it may be prudent to continue to measure fabric drape by established protocol for fabric characterization. Since there was so much difference in fabric behavior due to the amount of fabric unsupported by body parts (drape overhang length), computer simulation of apparel draping for patternmaking would benefit from data collected from specimens with greater drape overhang lengths.

Collier (1991) used two different platform diameters, 5 and 3 inches, to produce drape overhang length differences with the same specimen (10 inch diameter). A higher precision (reliability) was found for measurements made with the 3 inch diameter platform. Change in platform diameters attributed a significant source of variation among drape values (Collier, 1991). Thus, an increase in 1 inch of drape overhang length contributes a significant difference in obtained drape values. Collier's (1991) study also indicated that fabric drape reliability increased with increased drape overhang length. Since very few apparel parts are 10 inches or less, it would be more compatible with end use to measure the drape of larger fabric specimens. Thus, it was concluded that the modified drapemeter increased potential measurement reliability and compatibility of fabric measurements with end use.

Statistical Hypothesis III: The shape of the platform, oval versus round, does not influence node counts and mean drape values of two medium weight fabrics.

Platform shape was found to influence drape values. Since the human body has more oblong areas than round areas that act as support for apparel, it was concluded that use of an oval platform might better represent fabric drape behavior at the body waist, shoulder, and neck.

Statistical Hypothesis IV: The radius of curvature of the edge of the platform does not influence node counts and mean drape values of two medium-weight woven fabrics.

The radius of curvature placed on the drape platform edge was found to significantly influence drape values. Fisher' LSD test results indicated that there were significantly different pairs. The significance is strongest when platform edge curvature changes from 0/16 inch radii to 2/16 inch radii. This significant difference in drape values between the two radii suggested that there was a need to have at least platforms edges with 0/16 and 2/16 inch radii.

Another significant difference in drape values was found between platform edges with 2/16 inch and 4/16 inch radii. Since the significant differences were found every 2/16 inch increments of curvature, it was concluded that future drapemeters have platforms with edge radii variations every 2/16 inch. Significant differences in drape values between drape testing with platforms with 0/16 inch radii and 1/16 inch radii revealed that a small amount of edge curvature could change the way fabric drapes on an object or body. Since there are no 90 degree angles on most human bodies, it might be an advantage to use a platform with both shape and curvature similar to the area of the body where the garment fabric will be supported.

CHAPTER 6: SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

Summary

The drapemeter developed by Fabric Research Laboratories (FRL) for fabric drape measurements uses a 4 inch circular platform having a perpendicular side or edge . The modified version has oval as well as circular platforms that have edges with varied radii of curvature allowing the fabric to drape from a surface more closely resembling the curves of the human body. The modified drapemeter also has four pedestals of different heights to support the platforms. The modified drapemeter has completely adjustable parts so that a variety of variables can be studied.

Different pedestal heights allow for larger than traditional samples to be measured. Fabric samples used in this study were circles with 10, 14, and 18 inches in diameter and ovals with 10 X 11 and 18 X 19 inch in diameter. Samples of different diameters were measured in order to determine the effects of drape overhang length and pedestal height on the node count and drape value. Sudnik (1972) used different sample radii in research involving his investigation of the FRL drapemeter but did not change pedestal heights. Collier (1991) studied drape overhang length by changing platform diameters but did not alter specimen size. Statistical analysis indicated that the modified drapemeter measures fabric drape as accurately as the FRL drapemeter. The modified drapemeter was found to be reliable for measuring drape. ANOVA factorial analysis revealed that pedestal height can be altered without concern for precision in drape measurement. Drape values were found to be greatly affected by fabric specimen overhang length. Statistical analysis also indicated that platform shape and platform edge radii make significant differences in drape values.

Research Implications

Goals for fabric and product testing concern the four factors of utility. All criteria for instrument utility was met by the modified drapemeter. The modified drapemeter is accurate and reliable. With minor trade-offs with operator comfort and time required for testing, the modified drapemeter was judged to be simple and inexpensive to use. The modified drapemeter measures fabric drape in a more realistic manner relative to drape in garments on the body than the FRL drapemeter.

Recommendations for Future Research

The purpose of this study was to develop a modification of the FRL drapemeter with interchangeable pedestals and platforms in order to investigate the effects of fabric overhang length, platform disk shape, and platform edge curvature on the drape values of woven apparel fabrics. Modification of the FRL drapemeter was a segment of ongoing research involving the development of a computer graphics simulation program which uses intrinsic geometry parameters and a data base consisting of measurements of fabric mechanical properties. The modified drapemeter will be used to obtain drape value measurements for a large variety of apparel fabrics. These drape values will be added to the data base in the computer graphic simulation program developed by Dhande et al. (1993). Photographs of fabrics draped on different platforms within the modified drapemeter will be used to compare computer graphic simulations of the same fabrics.

The modified drapemeter could be used as a drape measuring instrument for other studies. Measurement of fabrics with opposing characteristics would be the next logical research step. Besides gaining support for the utility of the modified drapemeter, the resultant data could be used as a data base for developing a computer graphics simulation program for patternmaking by the draping method.

Another study needs to be conducted to learn more about the influence of fabric drape overhang lengths to obtained fabric drape values. Such a study could compare drape values obtained from platforms with larger diameters to drape values obtained from platforms of standard diameter supported by taller pedestal heights. In order to make a comparison, fabric specimen diameters would need to be equal. The influence of fabric drape overhang lengths for oval specimens with 18 x 19 inch diameters on drape values needs to be investigated. Another study is needed to address the influence on drape values created by increasing drape overhang length by 1/2 inch increments.

Another area with potential for research would involve the comparison of shadow diagrams obtained from the modified drapemeter with those obtained from computerized photographic or video imaging. The required equipment for such a study is presently commercially available.

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APPENDIX A

PHOTOGRAPHS DEPICTING VERSATILITY OF MODIFED DRAPEMETER

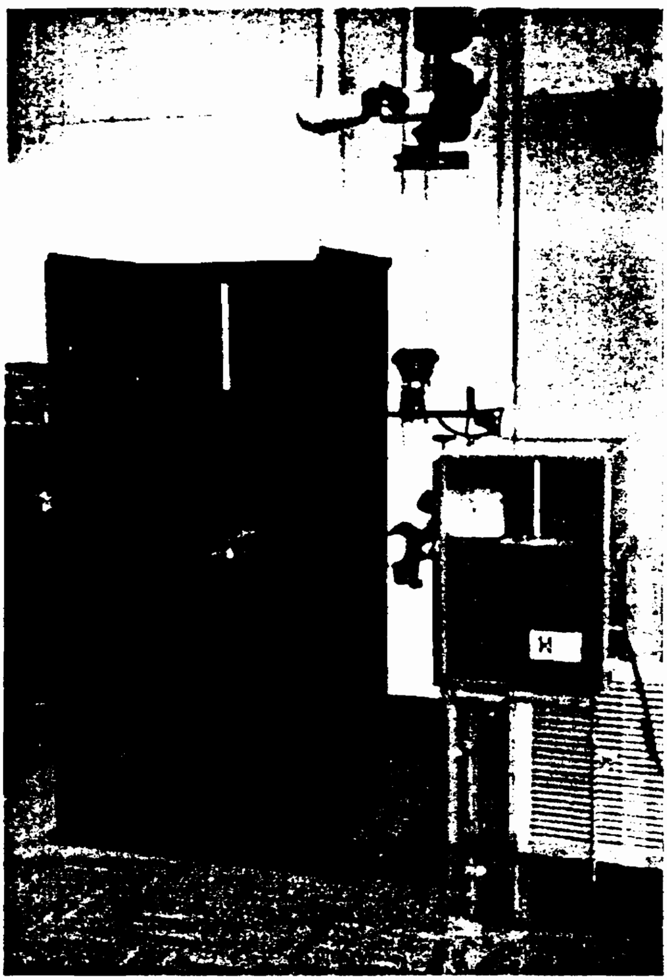

Figure 6. Comparison of FRL and Modified Drapemeters.

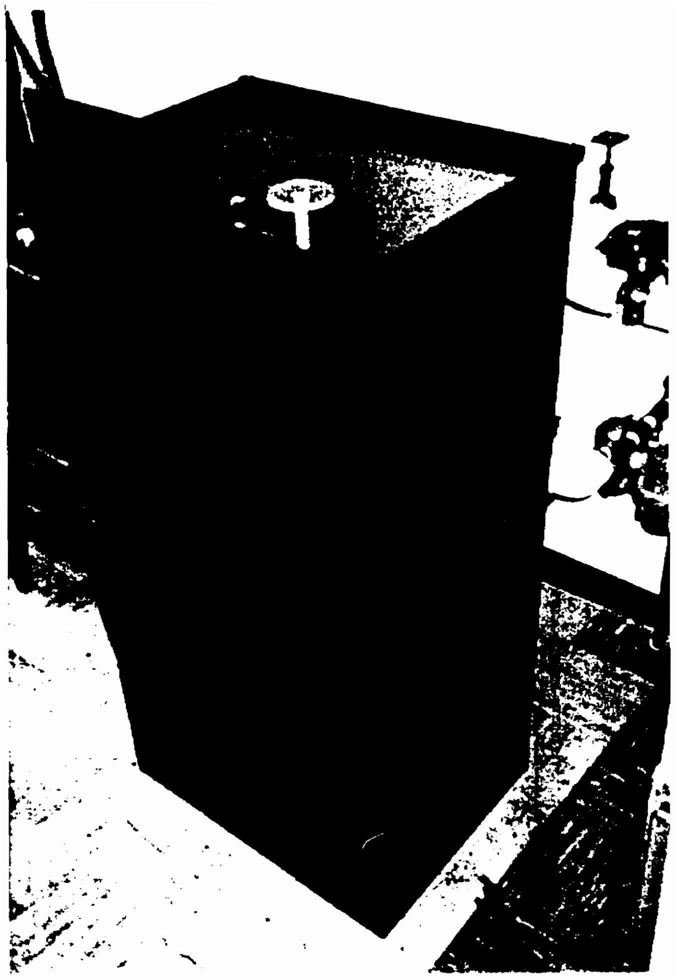

Figure 7. VPI&SU Modified Drapemeter in Standard Position for Drape Diagram Tracing.

Figure 8. Modified Drapemeter with Both Doors Open.

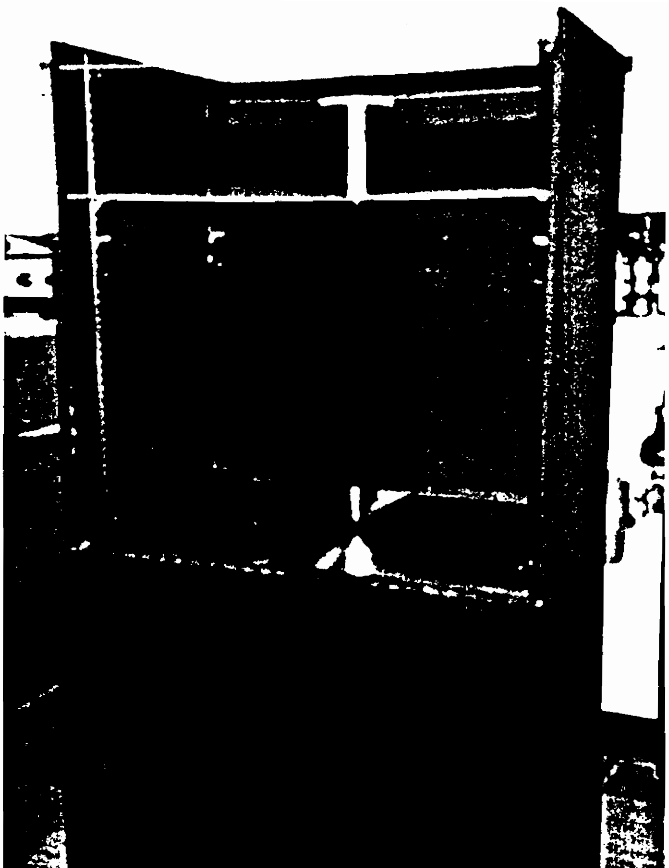

Figure 9. Modified Drapemeter with 5 Inch High Pedestal and Circular Platform with No Edge Radii.

Figure 10. Modified Drapemeter with 7 Inch High Pedestal and Circular Platform with No Edge Radii.

Figure 11. Modified Drapemeter with 9 Inch High Pedestal Drape Testing a 10 Inch Diameter Cardboard Circle.

APPENDIX B

DEVELOPMENT OF LOWER TRUNK HAlF-SCAlE MANIKIN SKELETON

The modified drapemeter is large enough to hold half-scale manikin parts. A half-scale skeleton of a manikin was built from waist down. (Instructions for building the manikin are in appendix A.) Fifteen half-scale straight skirts were tried on the manikin. Shadow tracings of each skirt's hem indicated the ability to study garment drape with the modified drapemeter. Other half-scale manikin parts could also be constructed and act as drape supports in the modified drapemeter. Fabric draping could be conducted with the manikin parts to get a more realistic drape measurement. The half-scale manikin and skirts were not a functional part of this research because there needs to be a study conducted for determining the drape coefficient when apparel shadows are measured as opposed to shadows of flat fabric specimens. Five hip plates were arranged one inch apart on the 23-inch pedestal to form a skeleton of a half-scale manikin from waist down. The contours of these plates were determined by measurements taken on a size fourteen half-scale manikin with a flexible ruler. Hip plates were constructed by drawing the contours on the 1/2 inch thick plexiglass and cutting on these contours with a bansaw. The hip plates edges were also sanded. The top hip plate served as the manikin waist contour. This top plate also acted as the draping platform for the manikin. A 1/4 inch diameter hole was drilled into the center of the waist plate. The lower four hip plates had a 1 1/4 inch diameter hole drilled in the center of each. These were placed on the tallest pedestal with a screw holding the bottom plate in place and metal spacers separating the other plates.

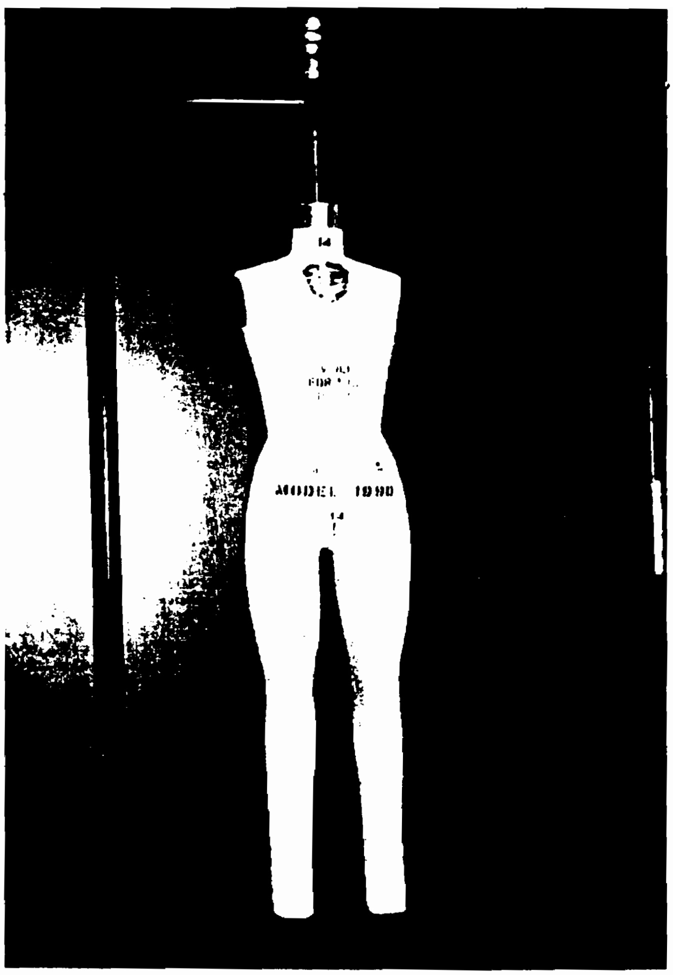

Figure 12. Size 14 Half-Scale Manikin.

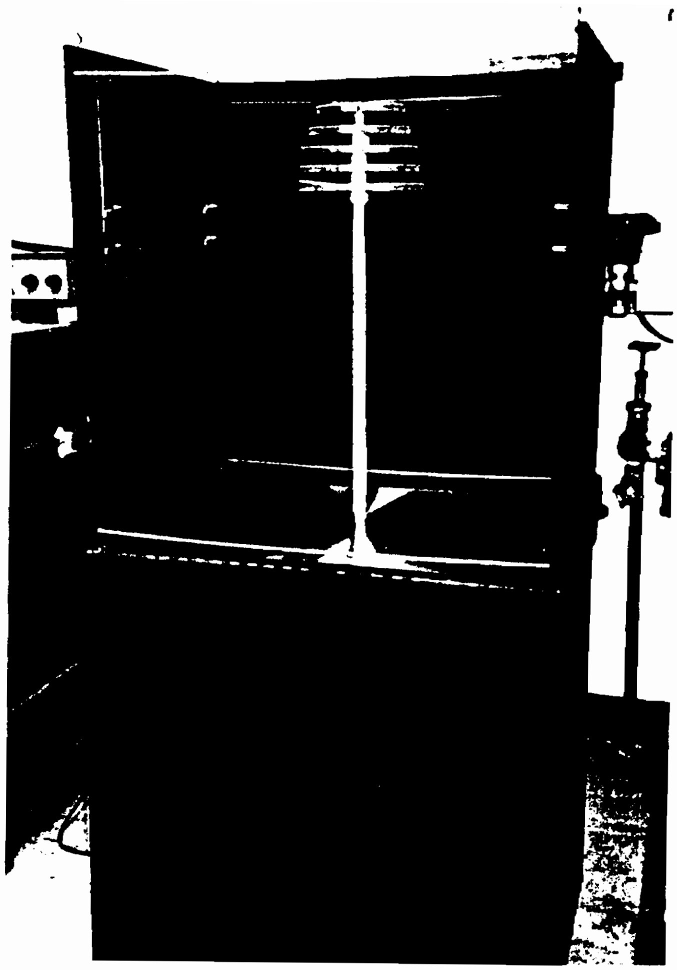

Figure 13. Size 14 Lower Trunk Half-Scale Manikin.

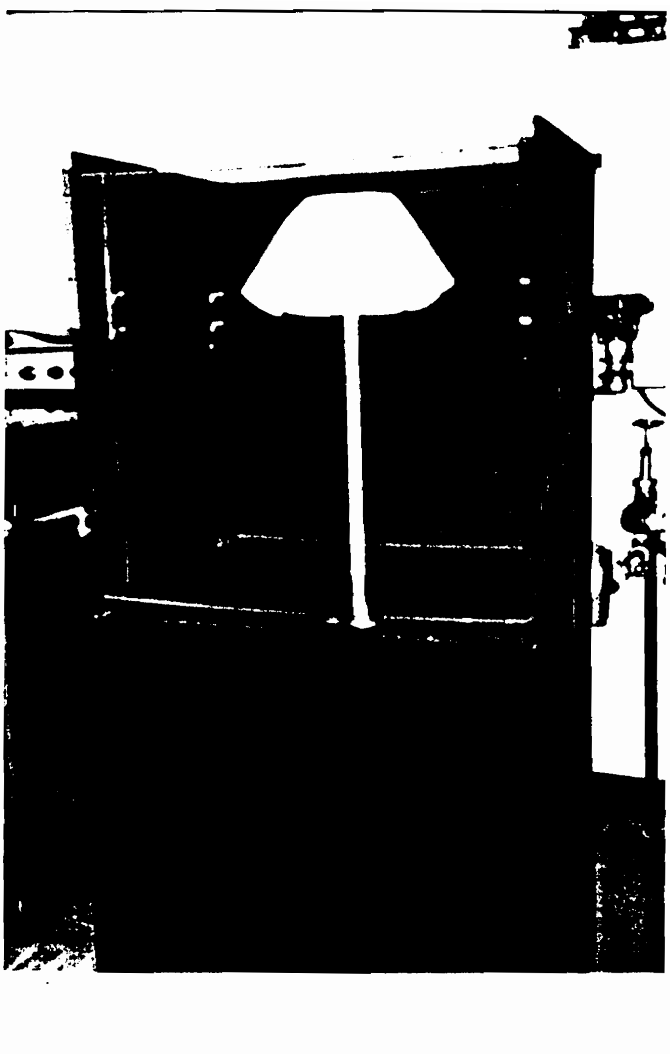

Figure 14. Oval Specimen (18 X 19 inch diameter) Draped over Lower Trunk Half-Scale Manikin.

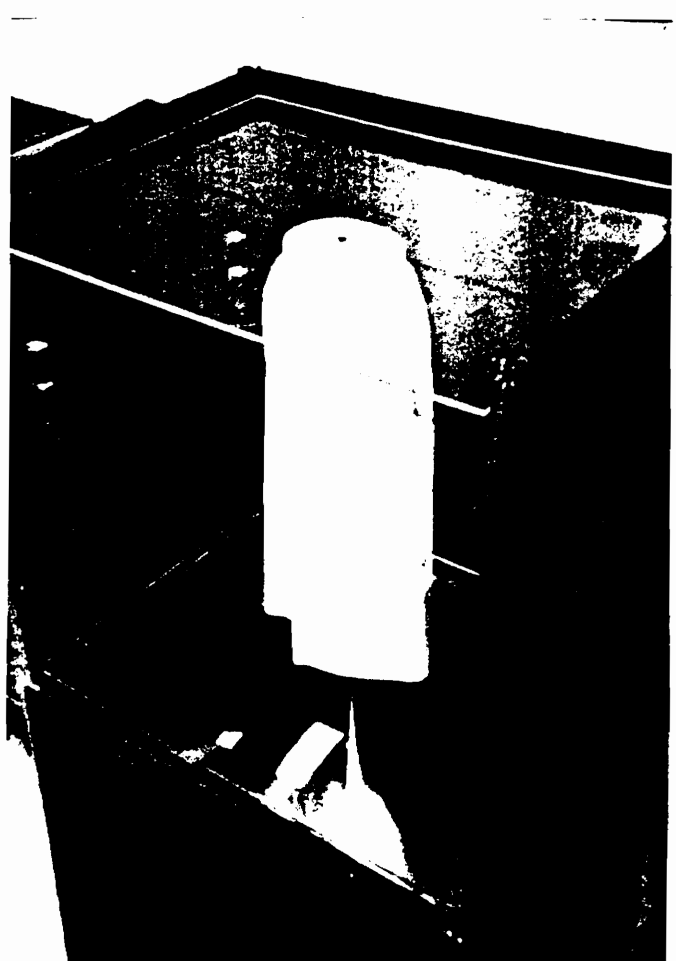

Figure 15. Size 14 Half-Scale Straight Skirt on Lower Trunk Half-Scale Manikin.

VITA

Sara L. Herbert

EDUCATION

M.S. 1994, Virginia Polytechnic Institute and State University, Blacksburg, Virginia;
  Major: Clothing and Textiles Apparel Design and Product Analysis (GPA: 3.8)
  Thesis: Measurement of Fabric Drape Using Modified Drapemeter
Attended 1991: O'More College of Design, Franklin, Tennessee
B.S. 1977, University of Tennessee, Knoxville, Tennessee
  Major: Vocational Home Economics Education
  Minors: General Science, Mathematics, General Business

PROFESSIONAl EXPERIENCE

1993-Present: Kappler Safety Group, Design Engineer
1991-1993: Virginia Polytechnic Institute and State University: Research Assistant - Relationship between fabric skew and apparel; Graduate Teaching Assistant - Textile Evaluation Lab; 1992: Glisson Historic Costume Collection, Blacksburg, VA: Internship
1979-Present (Leave of Absence): Williamson County Board of Education, Franklin, TN: Taught Home Economics, Algebra, Health
1978-1979: Metro-Nashville Public Schools, Nashville, TN: Taught Home Economics, Art, English
1977-1978: Cain Sloan Department Store, Nashville, TN: Bridal Consultant
1976-1977: University of Tennessee, Knoxville: Student Health Clinic
1970-1976: J.C. Penney Co., Nashville, TN: Model, Sales Clerk

PROFESSIONAl ORGANIZATIONS

American Association of Textiles Chemists and Colorists
RA8 Committee on Wettability
Past Vice-president for VPI&SU Chapter
American Society for Testing and Materials
F23 Committee on Protective Apparel - Human Factors Sub-committee
International Textiles and Apparel Association
American Education Association - Representative for Williamson County Chapter
American Home Economics Association
Past Treasurer for Middle Tennessee Chapter

ACTIVITIES AND HONORS

Virginia Polytechnic Institute and State University: Clothing and Textiles Graduate Student Assembly, Vice-president; Graduate Representative, Academic Affairs Committee for College of Human Resources and for Clothing and Textiles Department; Oris Glisson Scholarship; Faculty Scholarship
American Association of Textile Chemists and Colorists Research Grant
Seminar of the Center of Independence, Roanoke, VA
Apparel Design Modifications for Physical Handicaps
Nominated for Graduate Teaching Assistant Award
Kappa Omicron Nu