GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: January 17, 1972

Project Title: Research on Improved Cotton Carpet Backing Fabrics

Project No: E-27-61.0

Principal Investigator Prof. W. C. Boteler

Sponsor: Cotton, Inc., Raleigh, N. C.

Agreement Period: From January 1, 1972 Until November 30, 1972

Type Agreement: Contract No. 71-544

Amount: \$50,000.00

Reports Required: Monthly Progress Reports; Quarterly Technical Reports; Annual Report (if extended beyond one year); Final Report

Sponsor Contact Person (s):

Technical Matters Mr. R. B. Cleaver Research Manager Cotton, Incorporated 3901 Barrett Drive Raleigh, N. C. 27609 (919) 782-6330

Other

Contractual Matters Mr. Arthur B. Bond Administrative Assistant Cotton, Incorporated 3901 Barrett Drive Raleigh, N. C. 27609 (919) 782-6330

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GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT TERMINATION

Date: ilay 31, 1973

Project Title Research on Improved Cotton Carpet Backing Fabrics

Project No: E-27-610

60 22

Principal Investigator: Prof. W. C. Boteler

Sponsor: Cotton, Inc.; Raleigh, N.C.

Effective Termination Date: ____November 30, 1972 (Contr. Expiration)

Clearance of Accounting Charges: _____ Final billing completed

Grant/Contract Closeout Actions Remaining: NONE

Assigned to: School of Textile myineering

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GEORGIA INSTITUTE OF TECHNOLOGY A. FRENCH TEXTILE SCHOOL ATLANTA. GEORGIA 30332

February 11, 1972

Mr. R. B. Cleaver Research Manager Cotton, Inc. 3901 Barrett Drive Raleigh, North Carolina 27609

SUBJECT: Contract No. 71-544, Georgia Tech Project No. E-27-610 Monthly Letter Report for January

Dear Sir:

Project personnel presently consist of Professor Ralph Lathem, Professor Gerald Fletcher, and graduate research assistants Frank Ko and James Satterfield. Professor Lathem will advise and assist in the area of yarn manufacturing and Professor Fletcher will advise and assist in the weaving of fabrics.

A search for literature pertinent to the problem has been completed. The few articles which related specifically to cotton carpet backing were concerned with sheeting and canvases, which are still used in the chenille and custom tufting industries.

The bibliography will be included in the first quarterly report.

There is little information available on the required filling strength for broadloom carpets. However, there is a rule of thumb which indicates from experience that filling strength after tufting should be at least 50 pounds per inch.

Since there are no data available on the strength of cotton fabrics due to tufting, a fabric was designed to provide some basic data. Since the 5/32 inch needle spacing is most commonly used, and 7 stitches per inch is a widely used stitch count, a 13×14 fabric will be made to provide basic strength loss data. The initial fabric will be made from 2.5 count singles yarns in both warp and filling. This fabric will weigh 7.2 Oz./Yd.² and while the filling strength may be marginal, the resulting data will be useful in planning more refined fabrics. Mr. R. B. Cleaver

To facilitate the weaving of the base data fabrics, 140 pounds of yarn made from nominal 1 inch fiber were obtained from a commercial spinner. This yarn is being wound on a loom beam by a commercial weaver in the interest of time. However, subsequent yarns and loom beams will be prepared at Georgia Tech.

It is anticipated that the base fabric will be available sometime in February for tufting and subsequent evaluation.

Respectfully submitted,

/Winston C. Boteler
Project Director

WCB/1mb

APPROVED:

James L. Taylor Director French Textile School

GEORGIA INSTITUTE OF TECHNOLOGY

A. FRENCH TEXTILE SCHOOL ATLANTA, GEORGIA 30332

June 23, 1972

Mr. R. B. Cleaver Research Manager Cotton, Inc. 3901 Barrett Drive Raleigh, North Carolina 27609

> Subject: Contract No. 71-544, Georgia Tech Project No. E-27-610 Monthly Letter Report for April

Dear Sir:

The P-3, P-4 and P-5 fabrics were completed, evaluated, and tufted during the month. The P-3, 14 x 14, roving x yarn fabric had a breaking strength of 104.7 in the warp direction and 119.5 lbs. in the filling direction. Fabric weight was 8.2 oz./yd.². The strength retention after fine gauge tufting was 93% for the warp and 67% for the filling. The P-4, 13 x 12, fabric, with 2.1 hank roving warp and 2.1 c.c. yarn filling, weighed 6.4 oz./yd.² and had breaking strengths of 94.2 and 56.4 lbs. in warp and filling directions, respectively. Strength retention after tufting was 97% in the warp direction and 88% in the filling direction. The P-5 fabric, with 2.1 hank roving in both warp and filling directions, weighed 6.73 oz./yd.². Fabric breaking strength was 94.2 lbs. for the warp and 82.7 lbs. for the filling. The strength retention after tufting was 94% in the warp direction and 77% in the filling direction.

The conclusion was drawn from the preliminary studies that the roving fabrics are easily woven and that the all roving backings have better tuftability than yarn fabrics.

The original objectives of the project require the optimum performance fabric to have the greatest tuftability at the lowest cost. From previous experience, it is known that successful dyeing, latexing, and backing of a fabric can be best accomplished with fabrics having high strength retention after tufting. The absolute strength after tufting is important because the fabric must withstand the tensile forces in the filling direction due to shrinkage on the tenter frame during drying after dyeing and during the latex curing process. Page 2

An experiment was designed in which the factors are needle gauge, fabric construction, and yarn linear density. Twelve fabrics will be required for this phase of the project. Twisting of the rovings required for these fabrics is in progress.

Respectfully submitted.

Winston C. Boteler Associate Professor

WCB/1mb

APPROVED:

James L. Taylor Dinector A. French Textile School

GEORGIA INSTITUTE OF TECHNOLOGY

A. FRENCH TEXTILE SCHOOL ATLANTA, GEORGIA 30332

June 26, 1972

Mr. R. B. Cleaver Research Manager Cotton, Inc. 3901 Barrett Drive Raleigh, North Carolina 27609

> Subject: Contract No. 71-544, Georgia Tech Project No. E-27-610 Monthly Letter Report for May

Dear Sir:

Wet strength and shrinkage tests were made to determine the importance of these parameters. The P-2-T-A tufted fabric was processed through a mock dyeing operation. The sample was held at 200° F for two hours and rotated in a laboratory dye beck. The additives included 1% Igepon-73 and 2% glacial acetic acid, but without any dye. The fabric was hung for one hour, partially dried by two passes through a squeeze roll, then evaluated for strength and dimensional change. There was no significant change in length and approximately a 2% shrinkage in the filling direction. The low filling shrinkage, compared to approximately 10% for the untufted fabric, is attributed to the restrictive influence of the nylon face yarns. The partially dried fabric, moisture content 41%, was evaluated for breaking strength. The wet fabric had a 40% increase in warp strength and a 9% increase in filling strength compared to the dry fabric.

Manufacture of the quantities of 2.1, 2.3, and 2.5 hank twisted rovings required for the experimental fabrics was completed during the month. Three of the 12 fabrics in the experimental program were also completed during the month, although they were not evaluated.

Respectfully submitted,

Winston C. Boteler Associate Professor

APPROVED:

James L. Taylor Director A. French Textile School

WCB/bbr

GEORGIA INSTITUTE OF TECHNOLOGY

A. FRENCH TEXTILE SCHOOL ATLANTA, GEORGIA 30332

September 25, 1972

Mr. R. B. Cleaver Research Manager Cotton, Inc. 3901 Barnett Drive Raleigh, North Carolina 27609

> Subject: Contract No. 71-544, Georgia Tech Project No. E-27-610 Monthly Letter Report for July

Dear Sir:

Fabrics 14, 24, and 34 were completed during July. All of the remaining ten fabrics were tufted on machine " Λ " and the remaining four fabrics were tufted on machine "B".

Tensile strength evaluations were completed on all the untufted fabrics. The tensile tests were delayed due to the failure and subsequent replacement of the jaw clamps on the Instron tester.

The computer program was completed during the month and as soon as the data are complete, the prepared data cards will be punched.

Respectfully submitted,

winston C. Boteler Associate Professor

APPROVED:

WCB/1b

W. Denney Freeston, Jr. Director School of Textile Engineering

A. French Textile School Georgia Institute of Technology Atlanta, Georgia

Quarterly Report No. 1 Cooperative Agreement No. 71-544 Research Project No. <u>E-27-610</u>

Research on Improved Cotton Carpet Backing Fabrics

Prepared for: Cotton, Inc.

Respectfully Submitted

Winston C. Boteler Associate Professor

APPROVED:

James L. Taylor Director A. French Textile School

June 15, 1972

Quarterly Report No. 1, Project No. E-27-610

I Introduction

This report covers the work accomplished on the investigation of improved cotton carpet backing fabrics during the first quarter of 1972. Much of the quarter's work was involved in the weaving and evaluation of fabrics to be used as preliminary standards.

II Literature Search

A search was made of the literature back to 1950 with little success. A number of articles were located which described the cotton fabrics used in tufting. However, the fabrics referred to were either relatively heavy canvases or light weight closely-woven fabrics used in the bedspread industry. In all, some 74 articles were located which related to cotton fabrics, but none described specifically any technical information related to broadloom tufted fabrics as used today.

III Experimental Program

The experimental program has been planned as follows:

A. Preliminary Studies (February - April)

It is anticipated that information obtained during the preliminary studies will permit the design of an experiment which will lead to the optimum fabric. The objectives of the preliminary experiments are to explore the possibility of using roving instead of yarn to form the fabric and to select the variables and determine the ranges and areas of exploration.

Collection of Data (May - August) Β.

Extensive experimentation will be conducted according to the experimental design selected. This experimentation will include the manufacture of rovings, sizing of warp yarns, weaving of fabrics, tufting at two needle gauges, characterization of roving and fabrics, and the plotting of data.

Results, Analysis, and Conclusion (September - November) С. Based on the experimental results, the best prediction equations will be developed using a stepwise regression analysis. The type of backing which has the optimum tuftability with respect to cost will be determined, and the conclusions and recommendations will be submitted in a final report.

IV Progress to Date

> The purpose of these experiments was to establish a base level from which to design a set of experimental fabrics. A series of 5 fabrics was planned for the preliminary experiments as follows:

Code*	Weave	Ends x Picks	Warp	Filling
P-1	Plain	14 x 12	Yarn	Yarn
P-2	Plain	14 x 14	Roving	Yarn
P-3	Plain	14 x 14	Roving	Roving
2-4	Plain	13 x 12	Roving	Yarn
P-5	Plaín	13 x 12	Roving	Rov ing

*The suffix T will be added to denote tufted fabrics, such as P-1-T. The tufted fabrics will be denoted by adding suffix A for fine

-2-

gauge tufting (5/64 in.) and B for medium gauge tufting (7 needles/in.).

A nominal 1 inch staple length cotton was used for the preliminary experiments. Specifications for the yarn and hard twist roving were as follows:

> Yarn Count = 2.5 Cotton Count Roving Count = 2.1 HANK Yarn Twist = 5 Turns Per Inch Roving Twist = 5 Turns Per Inch

An attempt was made to weave the fabrics without sizing the warp yarns, however, due to excessive warp yarn breakage, the experiment was unsuccessful. The warps were then sized on a Callaway Model 50 slasher with 3 oz./lb. concentration of Hercules CMC size. After several trials, it was determined that a yarn speed of 5 feet per minute, cylinder speed of 3 rpm, and average temperature of 200°F were the optimum operating parameters.

The unsized yarn and roving were tested according to ASTM Method D-2256-69, with the following results.

	Yarn	Roving
Linear Density	2.5 c.c.	2.1 HANK
Twist	5 T.P.I.	5 T.P.I.
Breaking Strength (lbs.)	5.1	8.9
C.V. %	12.3	11.4
Elongation, %	10.6	8.6
C. V. %	7.6	29.4

The gauge length was 10 inch; chart speed was 10 in./min.; head speed was 10 in./min.; and 30 observations were made on each set of samples.

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The strength of the warp was increased as shown by the test data for the sized warp yarns: breaking strength, 5.3 lbs., C. V. 13.2%. After sizing, the warp was set up in a Draper X-2 loom and the fabrics woven according to the following specifications.

Loom:Draper X-2Fabric Width:36 InchesReed Width:44.75 InchesEnds x Picks/inch:14 x 12 FinishedLoom Speed:190 Picks/Min.

The actual weight of the 14 x 12 P-1 fabric, which was woven with yarn in both warp and filling, was 5.44 oz./yd.^2 . The fabric was evaluated for strength with grab break tests on an Instron testing machine. The test specifications were as follows.

Type of Test:Grab BreakConditions: $70^{\circ}F$, 65% R.H.Full Scale Load:100 lbs.Gauge Length:3 InchesJaw Speed:1 in./min.Chart Speed:10 in./min.Fabric Dimension:4 in. x 8 in.

Number of Observations: 5 Warp, 5 Filling The number of observations was a preliminary selection to determine the coefficient of variation and to determine the total number of

observations required to produce statistically valid results.

-4-

The following data resulted from the preliminary Instron tensile test for the P-1 fabric.

WARPWISE				FILLINGWISE					
	Strength	<u>Crímp%</u>	Yarn Elong. %	Total <u>Elong.</u>		<u>Strength</u>	<u>Crimp%</u>	Yarn <u>Elong. %</u>	Total <u>Elong.</u>
x	82.4	4.38	7.93	12.31		49.5	9.48	12.92	22.4
	5.43	0.72	0.48	1.63		4.58	0.41	0.83	0.88
%C.V.	7	16	12	13		9	4	6	4
Max.	90.0	5.3	9.6	14.9		55	10.2	13.8	23.1
Min.	80.5	3.53	7.06	10.83		44.5	9.2	11.6	20.9
Range	9.5	1.8	2.5	4.1		10.5	1.0	2.2	2.2

Assuming a 4% error, with the above mean values, standard deviations, and coefficients of variation, according to ASTM D-2264, 20 observations would be required for a 95% probability level.

The rovings were sized and woven in the same way as were the yarns. The roving strength did not increase significantly after sizing, 7.1 lbs. vs. 7.0 lbs., but the weaveability did improve considerably.

The specifications and properties of the P-2 fabric are listed below.

A. Physical Properties

Fabric Construction:	14 x 14, plain
Weight/Square Yard:	7.11 oz.
Warp:	2.1 HANK, Hard Twisted Roving
Filling:	2.5 c.c. Yarn
Twist:	Yarn, 5 T.P.I.

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1. Warpwise

- a. Average Breaking Strength: 95.8 lbs., 12.6%C.V.
- b. Crimp: 7.3%, C.V. 24.7%
- c. Yarn Elongation: 9.5%, C.V. 14.7%
- d. Fabric Elongation: 17.0%, C.V. 16.7%

2. Fillingwise

- a. Average Breaking Strength: 64.8 lbs., C.V. 6.9%
- b. Crimp: 8.9%, C.V. 17.8%
- c. Yarn Elongation: 12.8%, C.V. 6.8%
- d. Fabric Elongation: 21.7%, C.V. 8.2%

The P-2 fabric is slightly stronger than the P-1 fabric in both warp and filling. The warp strength increase is due to the greater strength of the roving, while the additional 2 picks/inch provides additional strength in the filling direction.

The two fabrics were tufted on the fine gauge machine (5/64 in. needle spacing) at 11 stitches per inch with 2600 denier nylon bulked continuous filament yarn. The fabric mechanical properties after tufting are listed below.

A. Fabric: P-1-T-A 14 x 12 Yarn x Yarn Warpwise Mechanical Properties

1. Average Breaking Strength: 75.3 lbs., C.V. 5.7%

2. Crimp: 9.6%, C.V. 12.0%

3. Yarn Elongation: 9.6%, C.V. 8.1%

v.

4. Fabric Elongation: 16.7%, C.V. 7.7%

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A. French Textile School Georgia Institute of Technology Atlanta, Georgia

Quarterly Report No. 2 Cooperative Agreement No. 71-544 Georgia Tech Research Project No. E-27-610

Research on Improved Cotton Carpet Backing Fabrics

Prepared for:

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Cotton, Inc.

Respectfully submitted

Winston C. Boteler Associate Professor

APPROVED:

W. Denney Freeston, Jr. Director

A. French Textile School

Quarterly Report No. 2 - Project No. E-27-610

I. Introduction

This report covers the work accomplished on the investigation of improved cotton carpet backing fibers during the second quarter of 1972. All but three of the 12 fabrics to be evaluated in the experimental program were completed during this period.

II. Experimental Program

Based on the result of the experimental fabrics evaluated in Phase I, the following experiment was planned.

FACTORS	LEVELS	ME A	SURED	LEV	/ELS		COD	E	·
Needle Gauge	2	13/	13/in.		7/in.		А		3
•									
Fabric Construction	4	14 x 14	13x13	13x12	12x12	1	2	3	4
Filling Linear Density* (Hank)	3	2.1	2.3	2.5		10	20	30	

*The warp rovings will be kept constant at 2.1. The warp yarn size may be varied later after optimum filling size is determined.

The total number of tufted fabrics to be evaluated is 24.

The experimental design matrix for the tufted fabrics is as follows:

11A	¢	21A	31A
11B		21B	31B
12A		22B	32 B
12B		22 B	32B
13A		23A '	33A
13B		23B	33B
14A		24A	34A
14B		24B	34B

-1-

The responses will be:

- (1) Breaking Strength
- (2) Elongation
- (3) Strength Retention

The data will be analyzed using the stepwise multiple linear regression technique - BMDO2R program on the Univac 1108 computer and the polynomial regression technique - BMD05R on the Univac 1108. A canonical analysis may be used to determine the response surface if necessary. The presentation of results will include the best regression equation, the multiple correlation coefficients and correlation matrix, the standard error of estimate, and analysis of variance table, and a plot of the residues versus the input variables. A cost prediction equation will be developed using real production costs from industry and the LaGrange multiplier method will be used to determine the optimum combination of factors with respect to cost.

The description of fabric constructions and codes for the second phase of the study are listed in Table I.

A number of tufting yarns were used during the first phase of the study and are listed below.

FIBER	DENIER	COTTON COUNT
Nylon (1 B.C.F. (2 (3)	1300 2600 3700	4.09 2.1 1.4
Nylon-Polyester Spun	4850	1.1
Acrylic (brown)	3600	1.48
Acrylic (white)	4622	1.14
Cotton	5595	0.95/2 ply

-2-

TABLE I

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UNTUFTED <u>FABRIC NO.</u>	CODE UNTUFTED FABRIC	CODE TUFTED FABRIC	FABRIC CONSTRUCTION ENDS x PICKS	ROV ING L INEAR DENS ITY WARP FILL ING	CALCULATED FABRIC WEIGHT OZ./YD. ²
1	11	11A 11B	14 x 14 .	2.1 2.1	8.24
2	12	12A 12B	13 x 13	2.1 2.1	7.36
3	13	13A 13B	13 x 12	2.1 2.1	6.72
4 [•]	14	14A 14B	12 x 12	2.1 2.1	6.35
5	21	21A 21B	14 x 14	2.1 2.3	7.74
6	22	22A 22B	13 x 13	2.1 2.3	7.20
7	23	23A 23B	13 x 12	2.1 2.3	6.64
8	24	24A 24B	12 x 12	2.1 2.3	5.97
9	31	31A 31B	14 x 14	2.1 2.5	7.00
10	32	32A 32B	13 x 13	2.1 2.5	6.56
11	33	33A 33B	13 x 12	2.1 2.5	6.16
12	34	34A 34B	12 x 12	2.1 2.5	5.80

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All yarns listed could be used on machine B (7 needles/inch), however yarns heavier than 1.48 cotton counts did not tuft well on machine A (12.8 needles/inch) due to numerous broken yarns.

Nine of the twelve fabrics have been completed. The three fabrics remaining to be woven are 14, 24, and 34. These fabrics will be completed before the end of July. Eight of the twelve "B" tufted fabrics have been tufted and two of the twelve "A" tufted fabrics have been completed. Failure of a part on the 5/64 inch delayed the tufting of the remaining ten fabrics, but it is estimated that they will be completed during July.

The 2.1 and 2.3 hank rovings were evaluated in June and the results are tabulated below.

	2.3 H.R.	2.5 H.R.
Breaking Strength	7.50	6.58
Elongation, %	9.53	8.76
Standard Deviation	0.70	0.59
% C. V. (strength)	9.37	9.01

These rovings were twisted to five turns per inch.

III. Future Plans

It is anticipated that all the fabrics will be completed during July and that all tufting and fabric evaluation will be completed during August.

School of Textile Engineering Georgia Institute of Technology Atlanta, Georgia

Quarterly Report No. 3 Cooperative Agreement No. 71-544 Research Project No. E-27-610

Research on Improved Cotton Carpet Backing Fabrics

1.

Prepared for:

Cotton, Inc.

Respectfully submitted,

Winston C. Boteler Principal Investigator

APPROVED:

W. Denney Freeston, Jr. Director School of Textile Engineering Quarterly Report No. 3, Project No. E-27-610

I Introduction

This report covers the work accomplished during the third quarter of 1972. The collection of tensile and elongation data was completed for all of the experimental fabrics. The computer statistical analyses of these data were completed during the reporting period.

II Experimental Program

a. Statistical Analysis

Analysis of all the tensile test curves was completed during July and August, as well as calculation of the average strength and elongation, coefficient of variation, and strength retention after tufting. During the month of September the collected data were keypunched onto computer cards for statistical analysis.

A stepwise regression analysis was made on the UNIVAC 1108 computer at the Computer Center of the Georgia Institute of Technology. The program used was a Biomedical Computer Program "BMD02R" which was prepared by personnel at UCLA (Dixon, W. J., Biomedical Computer Programs, University of California Press, Berkeley, 1971). Tufted fabric strength, elongation, and strength retention were investigated with respect to machine gauge (mc), construction (c), filling linear density (D), and interaction of construction and linear density (CD). The results are shown on Table I.

The needle spacing does not have a significant effect on warpwise strength. There is a strong influence due to fabric construction and filling linear density interaction of the two variables; fabric construction has a greater effect on the tufted fabric warpwise strength

	Description	Regression Equation	Multiple Correction Coefficient	% Variation Explained	95% Confidence Limit	Level of Significance
1.	Warpwise Strength	WS = 16.41+0.25+18.23D	0.83	69.5	±12.2	≫ 95%
2.	Fillingwise Strength	FS = 136.77-9.97NC+0.08C -43.79D+0.09D	0.90	80.4	±10.4	≫ 95%
3.	Warpwise Elongation	WE = 23.05-1.48MC+0.01C -6.48D+0.03CD	0.67	61.4	± 3.00	> 95%
4.	Fillingwise Elongation	FE = 22.38-3.17MC+1.78D	0.67	44.6	± 5.7	> 95%
5.	Warpwise Strength Retention	WSR = 54.4+0.53+34.19D -0.1CD	0.81	65.9	± 8.9	> 95%
6.	Fillingwise Strength	FSR = 49.72-0.96MC+0.13C +25.24D	0.73	54.0	±12.5	> 95%

TABLE ISTEPWISE REGRESSION RESULTS

than filling linear density. The tufted fabric warpwise strength increases with the increase of ends and picks per inch and the filling linear density.

The tufted fabric fillingwise strength is affected significantly by changes in machine needle spacing. As expected, the closer needle spacing causes more damage to the filling yarns. The most significant factor affecting tufted fabric fillingwise strength is the ends and picks per inch.

The filling linear density also affects the filling strength significantly. As the filling hank number increases, the fillingwise strength decreases.

The combination of variables listed in the hypothetical model accounts for 61% of the variation of warpwise elongation due to the responses. The ends and picks per inch affect tufted fabric warpwise elongation significantly. The warpwise elongation of the tufted fabrics increases as ends and picks per inch increase. The needle spacing affects the warpwise elongation of the tufted fabric. Fabrics tufted on the machine with closer needle spacing have lower elongations. Filling linear density and fabric construction -linear density interaction affect warpwise elongation, but only to a minor degree. An increase in the filling hank number causes a decrease in warpwise elongation. Only 45% of the fillingwise elongation is accounted for by the assumed computer model. Of all the variables, only needle spacing has a significant effect on fillingwise elongation. Fabrics tufted on the finer gauge machine have lower filling elongations. The filling

-3-

linear density, fabric construction and linear density-construction interaction do not have a significant effect on the fillingwise elongation.

Strength retention of the fabric after tufting is of highest importance. In jute backed carpets and unlubricated woven polypropylene carpets, the loss of filling strength after tufting is a serious processing problem. Generally, cotton backing fabrics have a much higher strength retention due to the relatively low modulus of the yarns and the relatively high breaking elongation of the cotton fibers. In the series of fabrics which was investigated, loss of strength after tufting is not a significant problem. On the average, strength retention values up to 84% were obtained in the fillingwise direction. Regardless of the insignificant strength loss, the effect of each of the variables can be examined based on the data from the explored experimental region.

The loss of strength in the warpwise direction is insignificant. This is due primarily to the needle configuration. Since the needle eye is parallel to the filling direction of the fabric as it passes through the tufting machine, the needle is relatively thin in the warpwise direction and thick in the fillingwise direction. Thus, the needle pushes aside the warp yarns, but many filling yarns are pierced or cut. The number of ends and picks has the greatest influence on the warpwise strength retention. With a lower number of ends and picks per inch, a fabric tends to have higher warpwise strength retention. Filling linear density has a significant effect on warpwise strength

-4-

retention. The strength retention increases with a decrease of filling linear density. In other words, a higher level of strength retention in the warp direction results if a smaller filling yarn is used. This increases the ability of the warp yarns to move away from the needle during fabric penetration.

As anticipated, fillingwise strength retention is lower than warpwise strength retention. There are no standards regarding minimum tufted fabric filling strength. However, values in the range of 50 to 60 pounds per inch have been suggested as standards by various groups. Many tufters have found that a filling strength of 50 lbs/in is necessary to insure that the fabric will not split on the tenter frame during the secondary backing or foaming process. Needle spacing is the dominant factor for fillingwise strength retention. As the needles are moved closer together, the fabric damage is increased. Ends and picks per inch and filling linear density affect fillingwise strength retention at about the same level, but'do not affect the strength as significantly as does needle spacing. A decrease in ends and picks per inch would increase the fillingwise strength retention. Fillings of higher hank roving number (finer roving) tend to increase the strength retention. The interaction of construction and linear density does not have a significant effect on strength.

Linear correlation analyses of the tensile properties were made with respect to weight per unit area of fabric, ends and picks per inch, and yarn linear density. The simple correlation equations relating the tensile properties and weight per unit area are shown on Table II,

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			95%
Response	Regression Equation	Correlation Coefficient	Confidence Limit
Untufted Warpwise			
Strength	UWS = 8.35W-42.21	0.71	±6. 11
Untufted Fillingwise	UFS = 17.07W-25.25	0.93	
Strength	UPS = 1/.0/W-23.23	0.93	±4.94
Warpwise Strength			
Regention . A Machine .	WSRA ≖ -5.19₩+137.14	-0.64	<u>+</u> 4.83
Warpwise Strength		1	
Retention B Machine	WSRB = -5.24W+136.07	-0.72	±3.69
Fillingwise Strength Retention			
A Machine	FSRA = -6.84W+126.73	-0.89	±2.59
Fillingwise Strength	-		
Retention		0.00	
B Machine	FSRB ≈ -2.19₩+104.10	-0.22	±7.13
Untufted Fabric			
Warpwise			
Elongation	UWE = 2.09W+0.90	0.80	±1.20
Untufted Fabric			
Fillingwise			
Elongation	UFE = -0.5W+21.62	-0.20	±1.53
Tufted Fabric	·		
Warpwise			
Elongation			
A Machine	TWEA = 2.43W+0.77	0.96	±0.52
	INDA LITONICI,	0.90	TO • JL
Tufted Fabric			
Warpwise			
Elongation			
B Machine	TFEB = 0.34W+23.58	0.11	±2.19

		TA	BLE IL					
<u>Tensile</u>	Properties	Versus	Weight	Per	Unit	Area	of	Fabric

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As expected, the strength of untufted fabrics increases as the fabric weight per unit area increases. The rate of increase in the fillingwise direction is faster than that in the warp direction. Both warpwise and fillingwise strength retentions, except for the fillingwise strength after tufting with the wide gauge machine (B), showed strong negative correlations with fabric weight per unit area. The strength retentions decrease significantly with increases in fabric weight. Untufted fabric warp elongation shows a high correlation with fabric weight, while the fillingwise elongation shows no significant change with change in fabric weight. Of the tufted fabrics, only the warpwise elongation for the fine gauge tufted fabric had a significant correlation with fabric weight.

The linear regression equations for the relationship between tensile properties and ends x picks per inch are shown on Table III. In general, the strength of the untufted fabric decreases as the ends x picks per inch of fabric increases. The rate of the strength decrease is faster in the filling direction. For the balanced fabric, warpwise strength is higher than fillingwise strength. These strength losses are attributed to the additional bending and consequent yarn elongation.

The relationships between the tensile properties and yarn linear density are listed in Table IV. The warpwise strength increases as the filling hank roving increases, while the fillingwise strength decreases with an increase in filling hank roving.

-7-

Response		Regres	sion Equa	ation	Correlatio Coefficien	n Con	95% fidence imit	
Untufted Fabric Warp Streng		UWS	≓ -6.70C	+115.9	-0.91		± 7.13	
Untufted Fabric Fillingwise		UFS	= -8.49C	+112.31	-0.74		±18.07	
Warpwise Stren Retention (A		WSRA	≖ -2.9 6C ⁻	⊦ 107.05	-0.59		±10.16	
Warpwise Stren Retention (1		WSRB	= -4.76C	+101.20	-0.65		± 8.07	
Fillingwise St Retention (4		FSRA	= -3.68C	+81.55	-0.62		± 8.91	
Fillingwise St Retention (1	-	FSRB	= -7.08C	₩98.63	-0.73		± 9.99	
Untufted Fabric Warpwise Elongation	c	UWE	= -1.02C	+17.88	-0.60		± 3.20	
Untufted Fabric Fillingwise Elongation	c	UFE	= -0.21C-	+ 19.54	-0.15		± 3.08	•
T ufted Fabric Warpwise Elongation	(A)	TWEA	⇒ -1.40 C-	1 20.83	-0.88		± 0.83	
Tufted Fabric Warpwise Elongation	(B)	TWEB -	≖ -0.95 C-	1 21.11	-0.47		± 4.22	
Tufted Fabric Fillingwise Elongation	(A)	TFEA	-0.19 C-	27.59	-0.10		± 4.16	
Tufted Fabric Fillingwise Elongation	(B)	TFEB	= -0.71C-	F27.69	-0.38		± 4.07	

TABLE III Tensile Properties Versus Ends x Picks Per Inch

			95%
Response	Regression Equation	Correlation <u>Coefficient</u>	Confidence Limit
Untufted Fabric Warpwise Strength	UWS = -4.20D+102.26	0.42	±3.63
Untufted Fabric Fillingwise Strength	UFS = -13.57D+134.29	-0. 68	±2.29
Warpwise Strength Retention (A)	WSRA = 4.04D+96.54	0.31	±3.52
Warpwise Strength Retention (B)	WSRB = 11.14D+85.82	0.72	±3.32
Fillingwise Strength Retention (A)	FSRA Ħ -2.36D+84.46 -	-0.22	±4.08
Fillingwise Strength Retention (B)	FSRB = -4.96D+100.21	-0.42	±3.49
Untufted Fabric Warpwise Elongation	UWE ≖ -2.79D+23.06	-0.82	±2.29
Untufted Fabric Fillingwise Elongation	UFE = -0.36D+19.5	-0.15	±3.08

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TABLE IV *	
Tensile Properties Versus Yarn Linear Density	

III <u>Future Plans</u>

It is anticipated that the cost data will be completed during November. A stepwise regression analysis will be made which will include cost as a variable. It is expected that these data will indicate which fabric has the highest strength retention at the lowest cost.

FINAL REPORT

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RESEARCH ON IMPROVED COTTON CARPET BACKING FABRICS

by

Winston C. Boteler . Frank Ko

Georgia Tech Project No. E-27-610 Cotton, Inc. Contract No. 71-544

Prepared for

Cotton, Inc. Raleigh, N. C.

January 1, 1972 to November 30, 1972

School of Textile Engineering Georgia Institute of Technology Atlanta, Georgia 30332

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ABSTRACT

A series of light weight cotton carpet backing fabrics was developed and evaluated. The properties of the resulting tufted fabrics indicated that suitable competitive backing fabrics could be manufactured if the fiber price remains at a reasonable level. The strength retention characteristics of the fabrics make their use for fine gauge tufting particularly attractive.

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I. Introduction

The objective of the project was to develop cotton carpet backing fabrics which would be competitive, particularly in fine gauge carpets. Synthetic fabrics have taken more than 50% of the primary backing market, due to a number of factors. The synthetic backings are relatively cheap, currently ranging from 17 to 26 cents per square yard. The relative inertness of the synthetic fabrics to biological degradation and dimensional change due to moisture have made possible the indoor-outdoor type carpets. However, a premium must be paid to insure that the backing is colored the same as the face yarns. This is presently accomplished in two ways: by using solution-dyed polypropylene backing and by needle punching a nylon fiber web onto the fabric face. Jute fabrics are either dyed prior to tufting or dyed in a separate bath after the face yarn has been dyed.

Cotton has the natural advantage of good yarn rupture elongation which made it desirable as a backing fabric during the early days of tufting. However, the early fabrics were relatively heavy and costly with respect to jute. Jute has the advantage of a higher modulus of elasticity, but the low rupture elongation causes a high strength loss when tufted at close needle spacings.

II. Summary and Recommendations

A number of fabrics were manufactured in the weights and constructions which previous experience indicated would be likely to meet the requirements of an economical fabric with suitable physical properties. Evaluation of data from the preliminary

tufted fabrics yielded sufficient information to permit the design of a controlled experiment using one size warp yarn and three different filling yarns. Twelve fabrics were woven and tufted at both fine and medium gauge needle spacings. The fabric weights ranged from 5.80 oz/yd² to 8.24 oz/yd².

The manufacturing costs were calculated using an 8 loom set-up as part of a larger cotton fabric mill. The costs were based on a fiber price of 30 cents per pound and a fabric width of 144 inches. The calculated labor costs ranged from 3.7 to 4.4 cents per pound, while the materials costs ranged from 16 to 19 cents per pound. The optimum fabric, selected on the basis of minimum total cost and maximum fillingwise strength retention, was a 13 x 13 fabric, with a 2.1 hank roving warp and 2.5 filling, weighing 6.56 ounces per square yard. The estimated manufacturing cost of the fabric is 20.6 cents per yard. The machinery requirements and cost breakdown are summarized in Table I and described in detail in Section VI of the report. A larger manufacturing scale would result in somewhat lower manufacturing costs. No comparable fabrics are listed on the commodity market. However, comparison with a recent selling price for 36-inch 20 x 12, 23 yds/lb, tobacco cloth permits some evaluation of the large scale manufacturing costs. The selling price of 5.26 cents per yard for the tobacco cloth included 1.3 cents per yard for fiber at 30 cents per pound. Thus, the production cost plus margin amount to only 4 cents per yard. Some additional economy would be effected by weaving a wider fabric, so that the large scale manufacturing cost for carpet backing should be no greater than the calculated range.

COST AND SUMMARY OF MACHINES REQUIRED

Warp/Filling Hank	1-2-2-2	2.1	/2.1	-	2.1/2.3			2.1/2.5				
Construction	14x14	13x13	13x12	12x12	14x14	13x13	13x12	12x12	14x14	13x13	13x12	12x12
Number of Looms	8	8	8	8	8	8	8	8	8	8	8	8
Number of Slashers	0.29	0.29	0.31	0.29	0.29	0.29	0.31	0.29	0.29	0.29	0.31	0.29
Number of Warpers	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Number of Winders Spindles	35	35	37	35	36	36	39	36	35	35	39	35
Number of Spinning Spindles	737	737	768	737	736	736	797	736	734	734	795	734
Number of Drawing (Del)	4.06	4.07	4.24	4.07	3.7	3.9	4.2	3.9	3.7	3.8	4.1	3.8
Number of Cards	7.5	7.5	7.8	7.5	7.1	7.2	7.7	7.2	6.9	6.9	7.5	7.2
Total Lbs/Wk (120 hr)	44717	44735	46715	44756	42893	42910	46487	42931	41360	41378	44826	41399
(Payroll: \$3120/wk) Labor Cost \$/lb.	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
Material Total Cost(30¢/lb),\$	13415.1	13420.4	14014.5	13426.8	12867.9	12873.	13946.1	12879.3	12408.	12413.4	13447.8	12419.
Lb/yd of Fabric	2.56	2.38	2.29	2.19	2.45	2.28	2.20	2.10	2.37	2.20	2.13	2.03
Labor Cost \$/running yd.	0.18	0.17	0.15	0.19	0.18	0.17	0.15	0.19	0.18	0.17	0.15	0.19
Material Cost (30¢/lb), \$/yd	0.77	0.71	0.69	0.80	0.74	0.68	0.66	0.78	0.71	0.66	0.64	0.76
Material & Labor Cost, \$/yd	0.95	0.88	0.84	0.99	0.91	0.85	0.81	0.97	0.89	0,82	0.79	0.95
-(Fabric Width 144") Fabric Weight, 1b/sq.yd.	0.64	0.59	0.57	0.55	0.61	0.57	0.55	0.53	0.59	0,55	0.53	0.51
Fabric Weight, oz/sq.yd.	7.7	7.1	6.9	6.6	7.4	6.8	6.6	6.3	7.1	6.6	6.4	6.1
Labor Cost/sq.yd., \$	0.045	0.041	0.038	0.038	0.045	0.041	0.037	0.038	0.045	0.041	0,037	0.038
Material Cost/sq.yd., \$	0.19	0.18	0.17	0.16	0.18	0.17	0.17	0.16	0.18	0.16	0.16	0.15
Material & Labor Cost/sq.yd.,\$	0.24	0.22	0.21	0.20	0.23	0.21	0.20	0.20	0,22	0,21	0.20	0.19

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The experimental fabric constructions are listed in Table II. A summary of the fillingwise fabric breaking strengths are listed in Table III. The "A" fabrics were tufted at 13 needles per inch and 10 stitches per inch, while the "B" fabrics were tufted at 7 needles per inch and 7 stitches per inch. The A and B tufting levels represent "contract" and "residential" type carpets, respectively. It can be seen from Table III that the untufted fabric strength decreases as fabric weight decreases, while the strength retention increases. The result is that strength after tufting is almost as high for the light weight 2.5 hank roving filling fabrics as for the heavier 2.1 H.R. filling fabrics. The optimum fabric was selected on the basis of strength retention for the "A", or fine gauge, fabric, since this needle spacing represents the most critical tufting condition in industry. Tables IV and V list the warpwise strength properties and elongations, respectively. It will be noted on Table IV that some warpwise strength retentions are more than 100%. This is due to the very few broken warp yarns and the additional inter-fiber friction produced by the insertion of the face yarn. The level of elongations shown on Figure V indicates the reason for the relatively high fillingwise strength retentions. The filling yarns are sufficiently elastic to avoid the tufting needles most of the time.

It is recommended that additional experiments be conducted to determine the behavior of these fabrics after tufting, backing, and finishing into complete carpets. In addition, some 12 foot broad loom fabrics should be woven, tufted, and backed, so that the completed carpets can be evaluated.

TABLE II

EXPERIMENTAL FABRIC CONSTRUCTIONS

No.	Fabric Code	Ends x Picks/in.	Filling Linear Density Hank	Fabric Weight oz/yd ²
1	11	14 x 14	2.1	8.24
2	12	13 x 13	2.1	7.36
3	13	13 x 12	2.1	6.72
4	14	12 x 12	2.1	6.35
5	21	14 x 14	2.3	7.74
6	22	13 x 13	2.3	7.20
7	23	13 x 12	2.3	6.64
8	24	12 x 12	2.3	5.97
9	31	14 x 14	2.5	7.00
10	32	13 x 13	2.5	6.56
11	33	13 x 12	2.5	6.16
12	34	12 x 12	2.5	5.80

Note: The warp linear density for all the fabrics is 2.1 hank roving.

All fabrics are plain weave.

TABLE III

SUMMARY OF FABRIC STRENGTH - FILLINGWISE

	Untufted Fabric	7	Tufted	Tufted Fabric			
	Lbs.	Breaking ^A	Strength	Breaking ^I	Strength		
Code	Breaking Strength	Strength	Retention(%)	Strength	Retention(%)		
11	179.52	79.9	67	93.97	79		
12	100.68	81.35	81	95.93	95		
13	82.69	65.15	79	63.89	77		
14	89.70	75.38	84	81.05	90		
21	109.54	83.55	76	93.38	85		
221	93.72	69.07	74	86.45	92		
2222	98.78	71.58	72	88.75	90		
23	85.58	66.38	78	82.93	97		
24	84.94	71.88	85	74.13	88		
31	92.38	75.23	81	84.05	91		
32	85.50	72.78	85	81.88	96		
33	74.30	63.45	85	73.55	99		
34	74.30	64.00	86	60.08	81		

TABLE IV

SUMMARY OF FABRIC STRENGTH - WARPWISE

í	Untufted Fabric		Tuft	ed Fabric	
	Lbs.	Breaking ^A	Strength	Breaking ^E	Strength
Code	Breaking Strength	Strength	Retention(%)	Strength	Retention(%)
11	107.67	97.02	93	96.07	92
12	98.45	100.13	102	93.55	95
13	94.16	91.78	97	88.28	94
14	89.71	93.35	104	90.20	101
21	114.24	111.73	98	109.88	96
221	102.72	96.60	94	103.58	101
²² 2	98.35	101.45	103	102.45	104
23	96.05	100.58	105	98.93	103
24	91.10	100.93	111	92.98	102
31	113.07	105.10	93	118.35	105
32	97.85	105.95	108	101.15	103
33	101.10	98.95	98	102.25	101
34	86.73	93.80	108	96.5	111

TABLE V

	Warpwise Ele			Fillingwise Elongation(%)				
Code		Tufted Fabric			Tufted Fabric			
	Untufted Fabric	A	В	Untufted Fabric	A	В		
11	20.34	19.94	21.01	19.40	21.59	25.58		
12	16.47	18.87	15.98	14.86	26.56	23.89		
13	14.53	16.85	13.45	17.58	18.72	24.46		
14	14.33	16.03	19.55	19.56	23.21	25.57		
21	17.36	20.16	21.92	21.29	22.95	27.69		
22 ₁	13.53	19.25	18.88	18.94	22.79	26.34		
²² 2	16.73	17.82	18.19	20.41	24.75	26.99		
23	16.18	16.05	19.63	19.11	20.10	24.52		
24	13.94	15.46	18.91	19.13	22,88	24.51		
31	14.70	17.92	20.20	20.03	21.93	26.20		
32	14.08	16.91	20.50	19.89	22.39	32.05		
33	15.07	15.97	18.24	19.32	19.23	24.94		
34	13.36	14.62	16.49	19.20	23.08	25.03		

FABRIC ELONGATION

III. Preliminary Study

The objective of the preliminary study was to get a general idea of the tuftability of cotton fabrics and to establish limits for a more detailed investigation. Relatively short and cheap fibers were used, and both yarn and hard twist rovings were examined as candidate warp and filling materials. The preliminary fabrics were woven as shown in the following table.

Fabric	Construction	Warp and	Filling
1	14 x 12	Yarn	Yarn
2	14 x 14	Roving	Yarn
3	13 x 12	Roving	Yarn
4	14 x 14	Roving	Roving
5	13 x 12	Roving	Roving

The yarns were 2.5 cotton count with 5 turns per inch of twist, while the rovings were 2.1 cotton count, also with 5 turns per inch of twist. The fabrics were tufted at both 13 needles per inch and 7 needles per inch gauges. It was found that the 2.1 hard twist roving was considerably stronger than the 2.5 C.C. yarn: 8.91 lbs. compared to 5.06 lbs. A preliminary tensile test on five samples indicated that, according to ASTM Designation D2264, 20 warp and filling specimens would be required to produce a 95% significance level.

The warp yarns were sized on a Callaway Model 50 slasher with 3 oz/lb of CMC. The slasher was operated at 3 rpm, giving a yarn speed of 5 feet per minute at an average temperature of 200°F. The fabrics were woven on a Draper X-2 loom at a speed of 190 picks per minute.

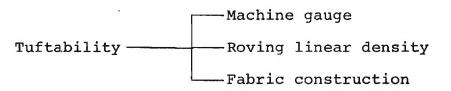
The preliminary experiments indicated that all the roving fabrics were superior to the yarn fabrics as carpet backings.

IV. Design of the Experiment

According to the main objective of the project, the experiment was designed to determine the lowest cost fabric with the highest tuftability.

Factors affecting each can be listed as follows:

- 1) Tuftability (in terms of strength retention)
 - T = f (Machine gauge, roving linear density, fabric construction)
- 2) Cost C = g (Raw material, processing) where raw materials, roving linear density and fabric structure are inter-related, as illustrated in the following diagram.



Cost ----- Raw materials

Therefore, the following experiment was developed.

Experimental Design

Factors	Levels	Meas	ured	Values		Code	
Needle Gauge (Needles/in.)	2	13 n/i	.n.	7 n/in	•	A B	
Fabric Construction	4	14x14 13	x13	13x12	12x12	123	4
Filling Linear Density (Hank Roving)	3	2.1	2.3	2.5		10 20	30
Warp rovings were the s	same, 2.1	H.R., for	all	fabric	5.		
Total number of experim	nents = 2	4					
Design Matrix for Tufte	ed Fabric	s = 11A 11B 12A 12B 13A	21A 21B 22A 22B 23A	31B 32A 32B	,		

13B

14A

14B

23B

24A

24B

33B

34A

34B

The responses were (1) breaking strength, (2) elongation, and (3) strength retention.

The variables of interest, region of exploration, and specific experimental levels were determined in the preliminary study. Since the selected region was based on experimental data, it was quite likely a near optimum region prior to investigation.

When several factors are involved in an experimental study, a factorial design is one of the most efficient ways of generating the required information. A two-factor, three-level (3^2 factorial) experiment was planned. The two factors are fabric construction and filling yarn linear density. All the fabrics were tufted on two different machines with different needle spacings (5/32 in. and 5/64 in.). The introduction of the machine variable suggests that there were two different blocks of data. A dummy variable, representing the machine, was inserted into the experimental design.

The coded and measured levels of the variables are listed in the following table.

		Coded a	nd Measur	ed Value		Code
Factors	Levels*	+1	0	-1	Units	Name
x _l Tufting Machine	2	A**	В			MC
x2 Fabric Construction	3	14x14	13x13	12x12	Ends x Picks per inch	С
\mathbf{x}_{3} Filling Linear Density	3	2.5	2.3	2.1	Hank	D

* +1 = High Level, 0 = Center, -1 = Low Level

**A = 5/64 Gauge, B = 5/32 Gauge

The design matrix in terms of coded values is as follows:

Experiment Number	Code Name	×l	×2	×3
1 2 3 4 5 6 7 8 9 10*	$ \begin{array}{c} 11 \\ 34 \\ 31 \\ 14 \\ 21 \\ 24 \\ 32 \\ 12 \\ 22-1 \\ 22-2 \\ \end{array} $		1 -1 1 -1 -1 0 0 0 0	-1 1 -1 0 0 1 -1 0 0
11 12 13 14 15 16 17 18 19 20	$ \begin{array}{c} 11 \\ 34 \\ 31 \\ 14 \\ 21 \\ 24 \\ 32 \\ 12 \\ 22-1 \\ 22-2 \\ \end{array} $	0 0 0 0 0 0 0 0 0	1 -1 1 -1 1 -1 0 0 0 0	-1 1 -1 0 0 1 -1 0 0

*An additional observation at the center of the design to check the experimental error.

From past experience it has been noted that the tensile response of a tufted fabric can be sufficiently described as a linear function of the backing structural properties. Therefore, a model was assumed to represent the fabric, where the true response "Y" is determined by the following equation:

$$Y = B_0 + B_1 X_1 + B_2 X_2 + B_3 X_3 + B_{23} X_2 X_3 + E$$
 (1)
Where B_0 = Constant Term

 B_i and B_{ii} = coefficients of ith and ijth variable X_1 = Machine Taype 1 = 5/64, 0 = 5/32 X_2 = Fabric Construction X₃ = Filling Yarn Linear Density X_2X_3 = Interaction between Fabric Construction and Filling Linear Density

E = Random Error Term

Y = Tensile Response of a Fabric, such as Absolute Strength, Elongation, and Strength Retention

The coefficients in Equation 1 were estimated by the method Then the estimates of the coefficients were of least squares. used to write the estimated response function, as follows;

 $\hat{Y} = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{23} x_2 x_3$ (2)Where b_i and b_{ij} are estimated coefficients

 x_1, x_2, x_3 and x_2x_3 are the variables listed above Y = Estimated Response

The specific program used to compute the data for this study on the Georgia Tech Univac 1108 Computer was the BMD 02R Stepwise Regression, compiled by UCLA. The program computes a sequence of multiple linear regression equations in a stepwise manner. At each

step one variable is added to the regression equation. The variable added is the one which produces the greatest reduction in the error sum of squares.

The added variable is also that variable which has the highest partial correlation with the dependent variable partialed on the variables which were added previously. Also, the added variable would have the highest F-value. Variables can be forced into the regression equation by setting a low F-value of inclusion.

In addition to the standard output which would be obtainable by a routine regression analysis, this program gives the following additional information:

- 1) Mean and standard deviation of the variables
- 2) Covariance and correlation matrix
- List of residuals and plots of residuals versus the input variables
- 4) Summary table

The correlation matrix shows not only the partial correlation between independent and dependent variables, but also the inter-relationships between the independent variables. The list of residuals indicates how close the predicted response is to the observed response, or experimental response. The residual is also an indication of the amount of experimental data which the regression equation has not been able to explain. An examination of the plots of residuals versus the dependent and independent variables helps to pinpoint the unexplained variables. The residuals can also serve as a means of verifying our assumptions about the error. (The usual assumptions are that the errors are independent, have a zero mean constant variance, and are normally distributed.)

v. Collection of Data

The 24 tufted fabrics were tested on the Instron tensile test machine to determine the relationship between load and elongation and to determine the breaking strength and elongation. The resulting data were plotted against the fabric variables and the data plots are included as Figures 1 through 32 in Appendix I.

The production data used to calculate the manufacturing costs were developed by assuming a set of 8 looms running 120 hours per week. The resulting production data are listed below.

Construction	<u>14x14</u>	<u>13x13</u>	<u>13x12</u>	<u>12x12</u>
Total Warp lbs/wk	24,474	24,763	26,828	24,785
Total Filling 2.1 Hank	24,019	24,019	24,019	24,019
Total Filling 2.3 Hank	21,931	21,930	23,758	21,930
Total Filling 2.5 Hank	20,176	20,176	21,856	20,176
2.1/2.1 Total lbs. Warp & Filling	44,717	44,735	46,715	44,756
2.1/2.3 Total lbs.	42,893	42,910	46,487	42,431
2.1/2.5 Total lbs.	41,360	41,378	44,826	41,399
Machines Required, 2.	1/2.1			
Slashers	0.29	0.29	0.31	0.29
Warpers	0.05	0.05	0.05	0.05
Winder	35	35	37	35
Spindles	737	737	768	737
Drawing Frames	4.06	4.07	4.24	4.07
Cards	7.5	7.5	7.8	7.5

	<u>14x14</u>	<u>13x13</u>	<u>13x12</u>	<u>12x12</u>
2.1/2.3				
Slashers	0.29	0.29	0.31	0.29
Warper	0.05	0.05	0.05	0.05
Winder	36	36	39	36
Spindle	736	736	797	736
Drawing	3.7	3.9	4.2	3.9
Cards	7.1	7.2	7.7	7.2
2.1/2.5		2		
Slasher	0.29	0.29	0.31	0.29
Warper	0.05	0.05	0.05	0.05
Winder	35	35	39	35
Spindles	734	734	795	734
Drawing	3.7	3.8	4.1	3.8
Cards	6.9	6.9	7.5	7.2

The labor costs in Table I are based on the following labor requirements.

Weavers 2 Slasher 1 Winder 1 Spinners 2 Carding 2 2 Drawing Open & Cleaning Total = 8 laborers at average \$3.25/hour Total Payroll = \$3120

VI. Analysis and Discussion of Results

The summary of the regression data is shown on Table VI. The computer print-outs are included as Appendix II to this report.

TABLE VI

SUMMARY OF STEPWISE REGRESSION ANALYSIS

	Description	Regression Equation	Multiple Correlation Coefficient	% Variation Explained	95% Confidence Limit	Level of Significance
1)	Warpwise Strength	WS = 16.41 + 0.25C + 18.23D	0.83	69.5	±12.2	>>95%
2)	Fillingwise Strength	FS = 136.77 - 9.97MC + 0.08C -43.79D + 0.09CD	0.90	80.4	±10.4	>>99%
3)	Warpwise Elongation	WE = 23.05 - 1.48MC + 0.01C -6.48D + 0.03CD	0.78	61.4	±3.0	>95%
4)	Fillingwise Elongation	FE = 22.38 - 3.17MC + 1.78D	0.67	44.6	±5.7	>95%
5)	Warpwise Strength Retention	WSR = 54.37 + 0.53C + 34.19D -0.1CD	0.81	65.9	±8.9	>95%
6)	Fillingwise Strength Retention	FSR = 49.72 - 9.96MC + 0.13C + 25.24D - 0.1CD	0.73	54.0	±12.5	>95%

MC = Machine Gauge Note:

C = Construction (Ends x Picks/inch) D = Filling Linear Density in Hank CD = C and D Interaction

The data summary gives a general idea of the relative contribution of all the variables entered into the regression equations. The square of the multiple correlation coefficient indicates how much of the response variation has been explained. The increases in the square of multiple correlation (RSQ) and the "F" value are the indicators of the relative significance of each entered variable. The sign of the estimated coefficient indicates the relationship between each variable and the corresponding response. A negative coefficient implies that the response increases with a decrease of the corresponding variable.

a. Warpwise Strength

The relationships between warpwise fabric strength and the fabric variables are detailed on Printout I in Appendix II. In general, warpwise strength is higher than fillingwise strength. Needle spacing was not a significant factor in warpwise strength.

Fabric construction and filling linear density show a strong influence on warpwise strength at the beginning of Printout I. But as soon as the individual factors are entered into the regression equation the interaction effect becomes insignificant. (This is indicated by the analysis of variance table in Printout I.) This indicates that the early sign of importance in the regression was due primarily to the individual factors, fabric construction and filling linear density. To verify this deduction, an additional analysis was made by entering only fabric construction and filling linear density, as shown on Printout II.

A multiple regression correlation coefficient of 0.834 was obtained, which indicates that 69.5% of the response variation was

contributed by the two variables. This can be compared with the results in Printout I, which show that the three variables, namely, fabric construction, filling linear density, and fabric constructionfilling linear density interaction, contribute 69.6% of the response variation. Considering the difference in the RSQ's* and the fact that the interaction effect vanished at the end in Printout I, it can be concluded that only fabric construction and filling linear density are significant to the response. Of the two, fabric construction has more effect than filling wise linear density on tufted fabric warpwise strength. Tufted fabric warpwise strength increases with an increase in ends x picks per inch and filling linear density.

b. Fillingwise Strength

The effect of needle spacing on tufted fabric fillingwise strength is significant, and as expected, the 5/64 inch fine gauge machine caused more backing damage and produced weaker fabrics. The machine type contributes 24.9% of the response variation out of a total of 80.36% variation due to all variables, as shown on Printout III. The most significant factor affecting tufted fabric fillingwise strength is the number of ends x picks per inch, which contributes 31% of the total response. Filling linear density also affects the fillingwise strength significantly, accounting for 22% of the response variation. As the filling hank increases, fillingwise strength decreases. The interaction of ends x picks per inch

^{*}RSQ = Square of Multiple Correlation Coefficient. RSQ = 0.8 means that 80% of the variation has been explained.

and filling linear density has a positive effect on filling strength, but it is a minor effect.

c. Warpwise Elongation

The combination of all the variables as proposed in the hypothetical model accounts for 61.39% of the response variation, as shown on Printout IV, which indicates that almost 40% of the variation remains unexplained. There may be some fiber translation which was not included in the model.

Ends x picks per inch have a significant effect on tufted fabric warpwise elongation, accounting for 36.7% of the response variation. Warpwise elongation increases as ends x picks per inch increases. Machine type contributes 17.6% of the response variation. Fabrics tufted on the fine gauge machine have lower elongations. The effect of fabric construction and filling linear density-fabric construction interaction is positive but not significant. An increase in filling hank number causes a decrease in warpwise elongation.

d. Fillingwise Elongation

Printout V shows that the hypothetical model explains only 45% of the response variation. Of all the variables, only machine type has a highly significant effect on the fillingwise elongation. It accounts for 43.26% of the response variation. The negative effect shown in the correlation indicates that fabrics tufted at fine gauge have lower elongations. Filling linear density has a positive effect, but not a significant one. Fabric construction and the interaction do not have a significant effect on fillingwise elongation.

e. Warpwise Fabric Strength Retention

There is no significant strength loss for the fabrics in the experimental region. An examination of the multiple correlation coefficient from Printout VI indicates that about 66% of the response variation has been explained. Ends x picks per inch have the greatest influence on the warpwise strength retention. Fabrics tend to have higher warpwise strength retentions as the ends x picks per inch are decreased. About 35% of the total response variation is explained by this variable. Filling linear density also has a significant effect on warpwise strength retention. It accounts for about 26% of the response variation. The warpwise strength retention increases with an increase in filling linear density (hank number). In other words, a higher level of strength retention can be achieved in the warp direction if a smaller size filling yarn is used. Interaction of the above factors is of only minor significance, and needle spacing is not a significant factor. f. Fillingwise Strength Retention

As anticipated, fillingwise strength retention is lower than warpwise strength retention. The average fillingwise strength retention for fabrics in this study was 84%. As shown on Printout VII, machine type, or needle spacing, is the dominant factor in fillingwise strength retention, accounting for 41% of the response variation. The fabric tufted strength decreases as needle spacing decreases. Ends x picks per inch and fillingwise linear density affect fillingwise strength retention at about the same level, but are not as significant as needle spacing. A decrease of ends x picks

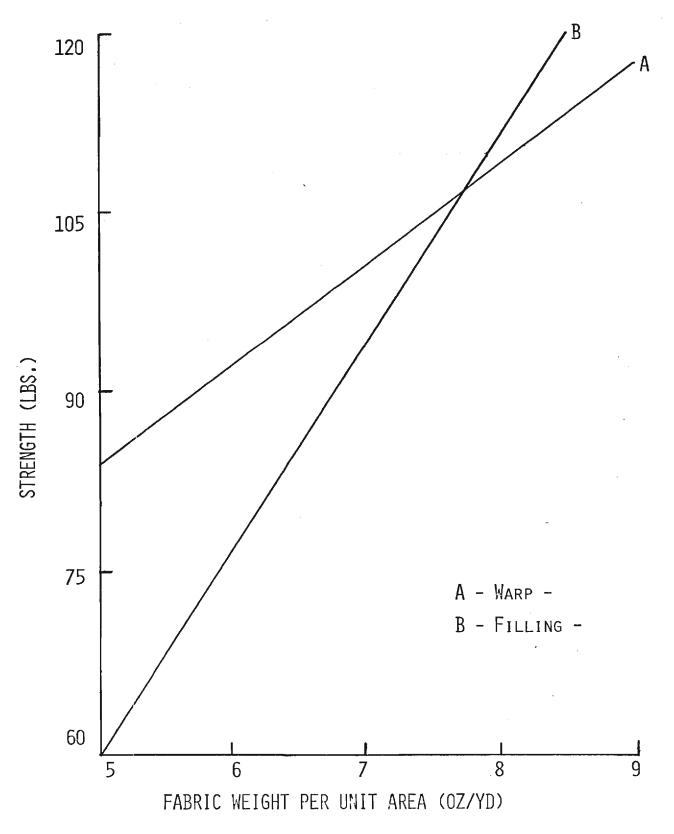
per inch causes an increase in fillingwise strength retention, and a finer filling roving with respect to the warp produces an increase in strength retention.

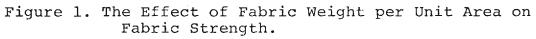
In summation, for warpwise strength retention, the fabric should have a high ends x picks per inch while keeping the hank number as low as possible. For maximum filling strength retention, the fabric should have a low ends x picks per inch and finer filling (higher hank number).

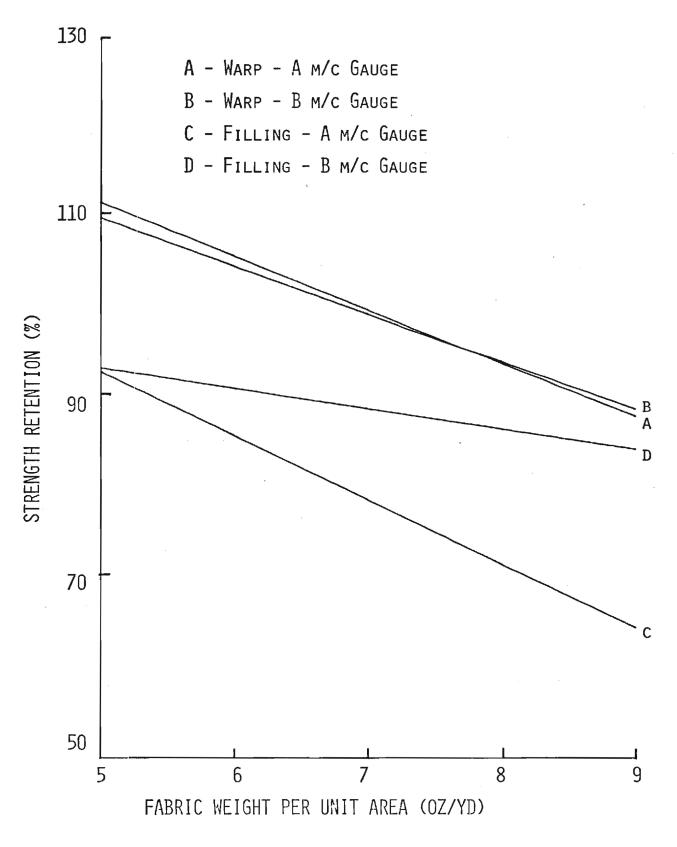
APPENDIX I

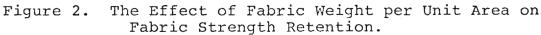
FABRIC DATA PLOTS

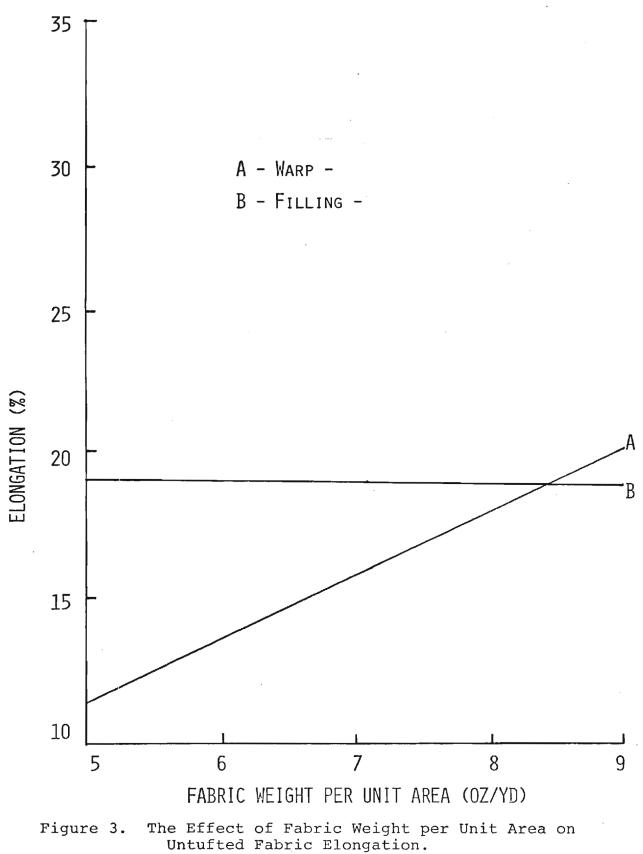
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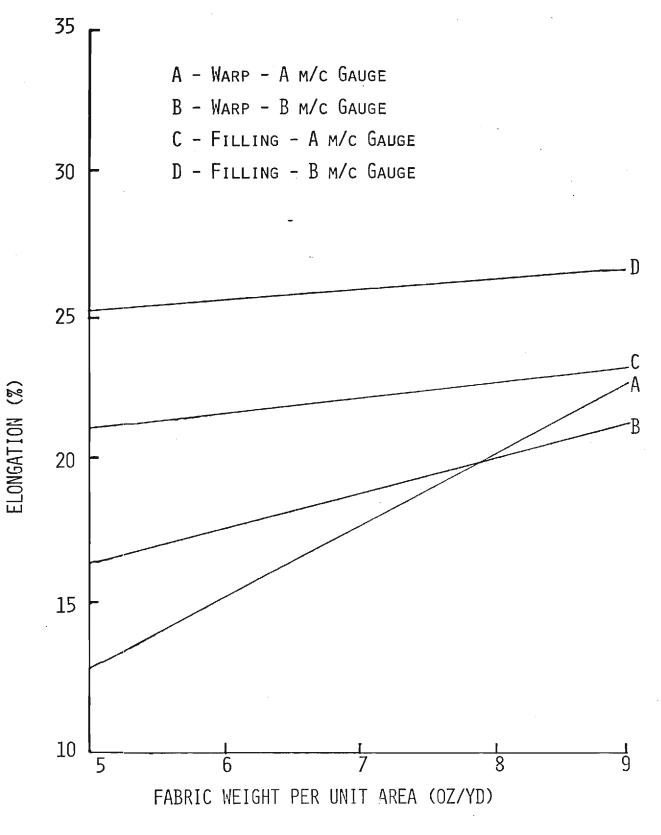
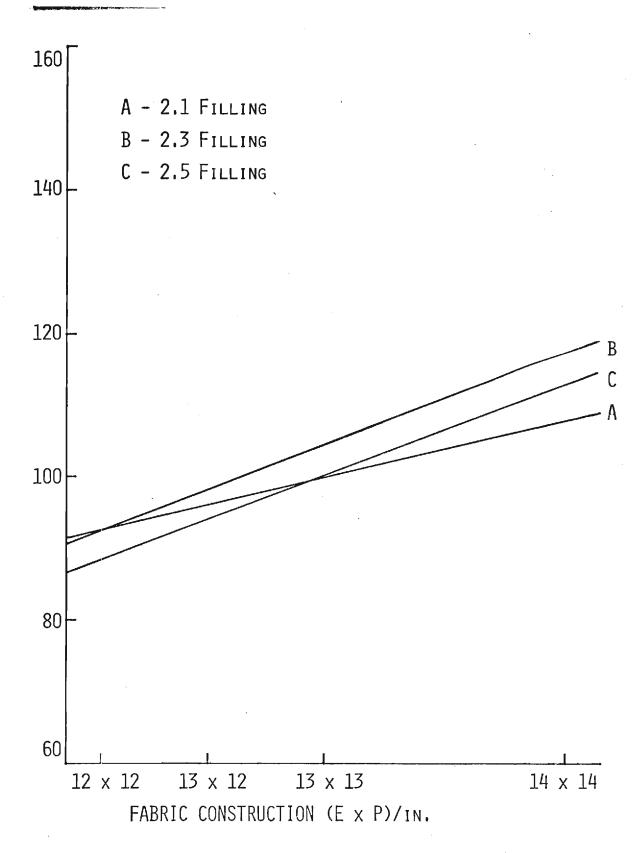
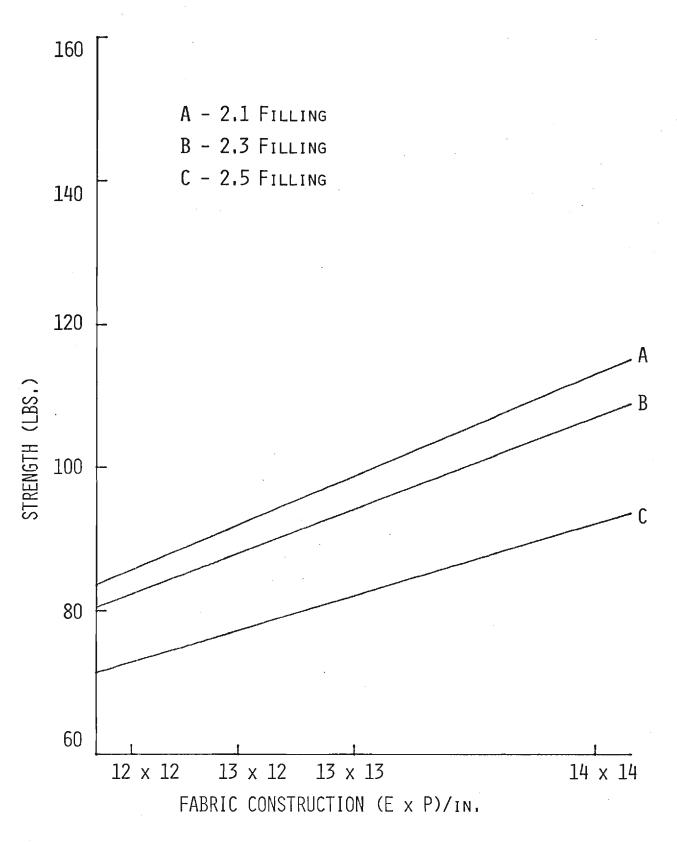


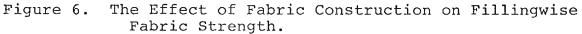
Figure 4. The Effect of Fabric Weight per Unit Area on Tufted Fabric Elongation.

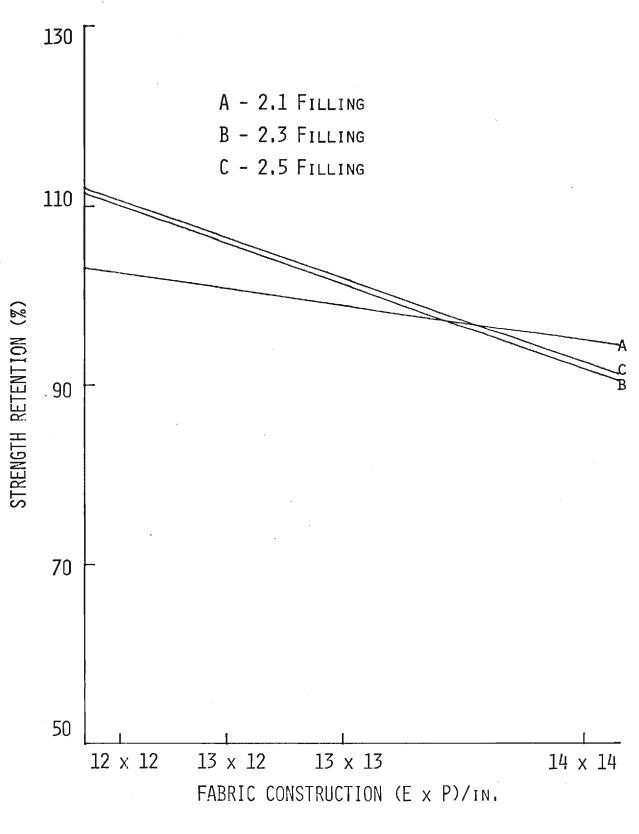


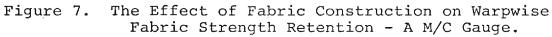
STRENGTH (LBS.)

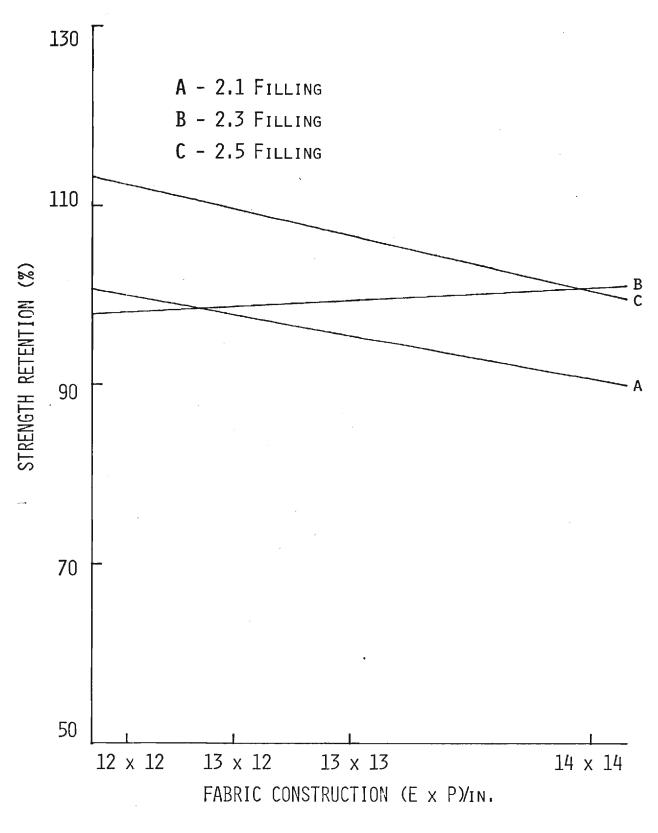
Figure 5. The Effect of Fabric Construction on Warpwise Fabric Strength.

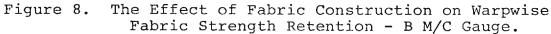


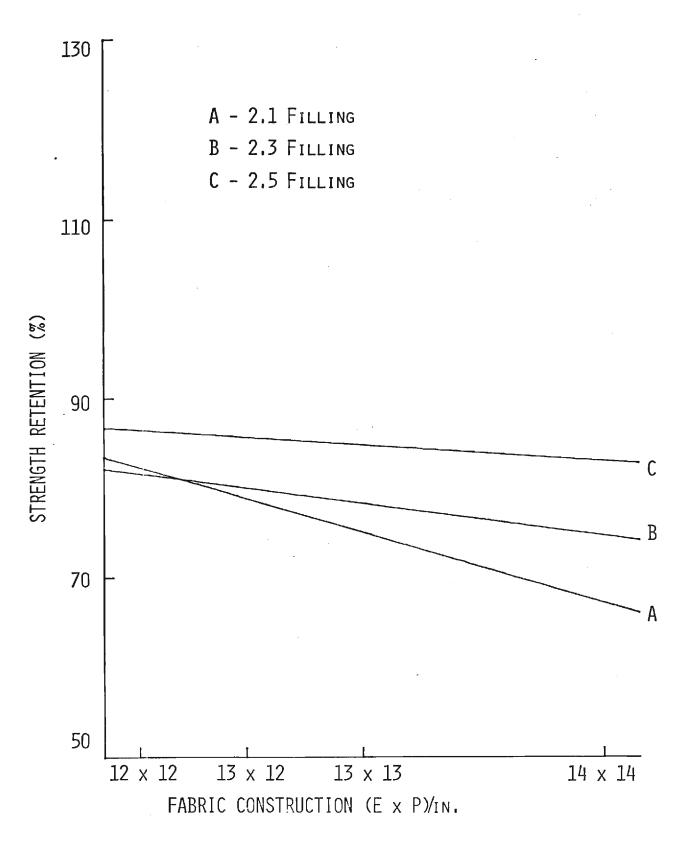


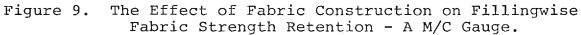


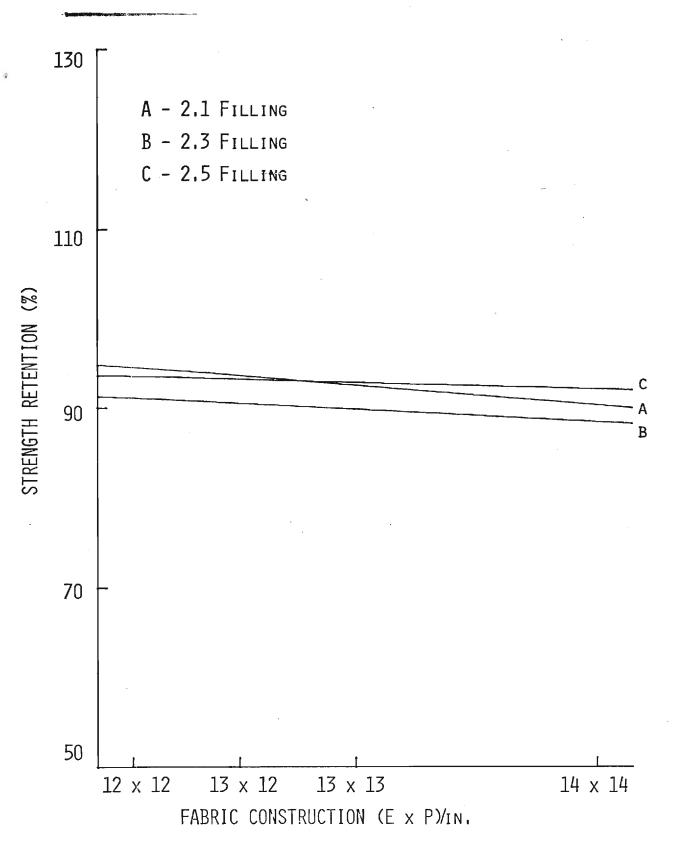


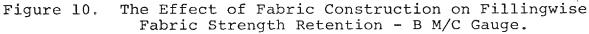












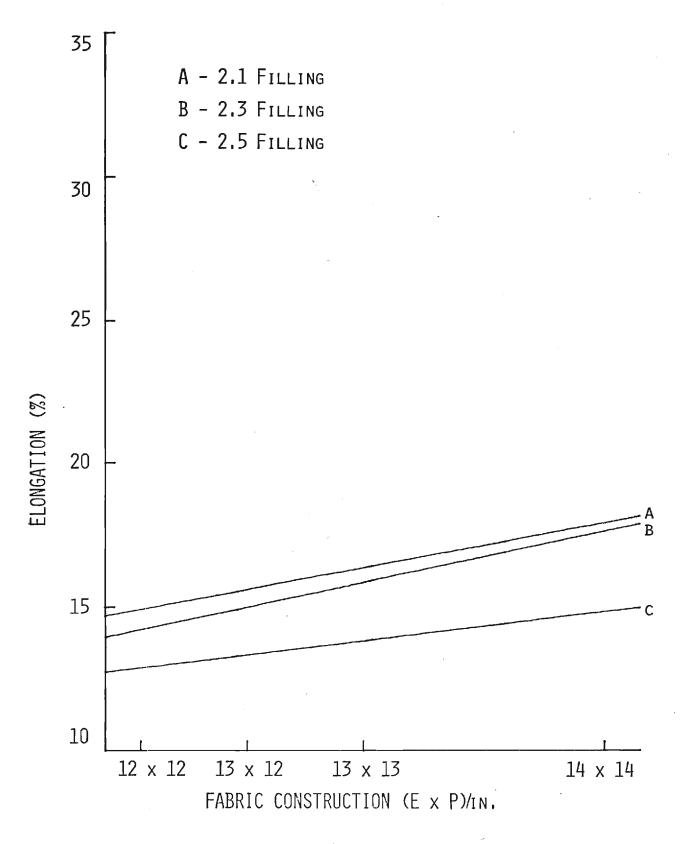
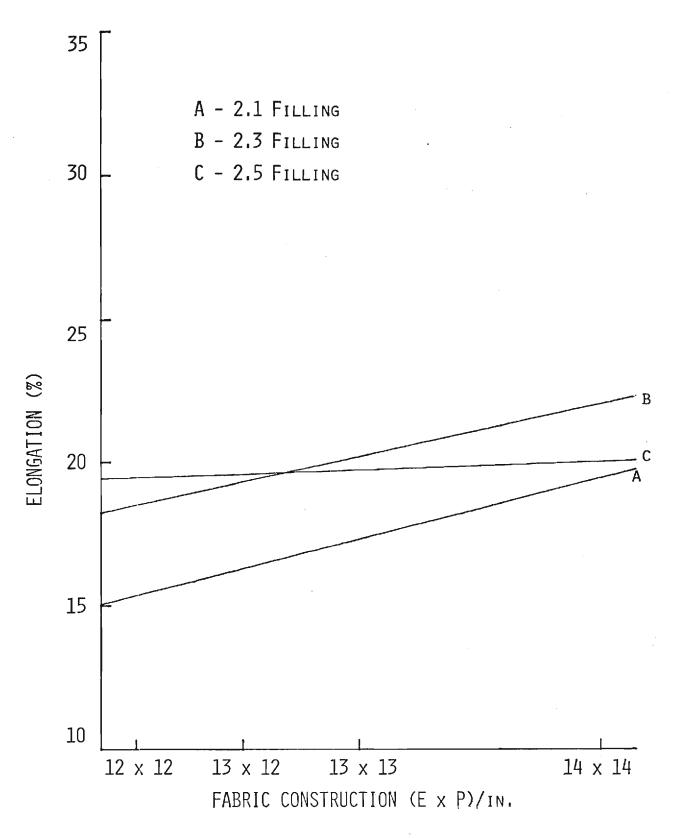
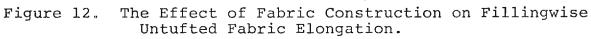
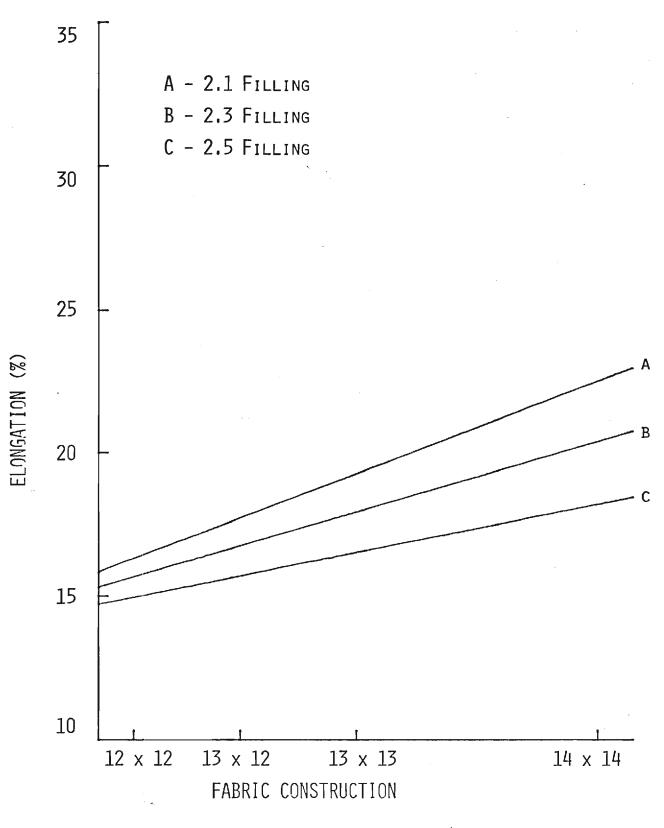
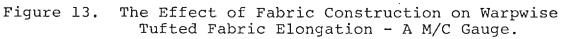


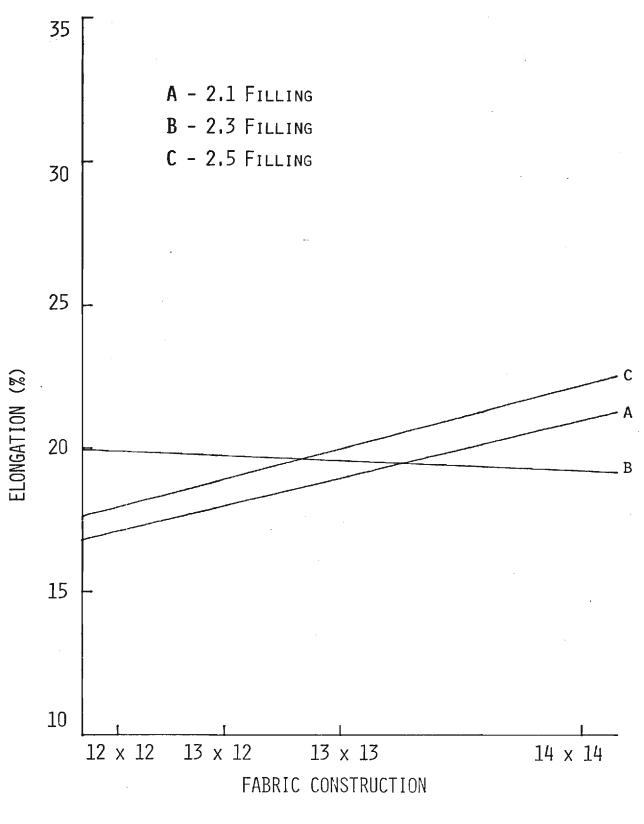
Figure 11. The Effect of Fabric Construction on Warpwise Untufted Fabric Elongation.

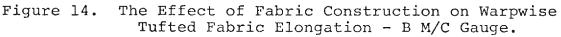


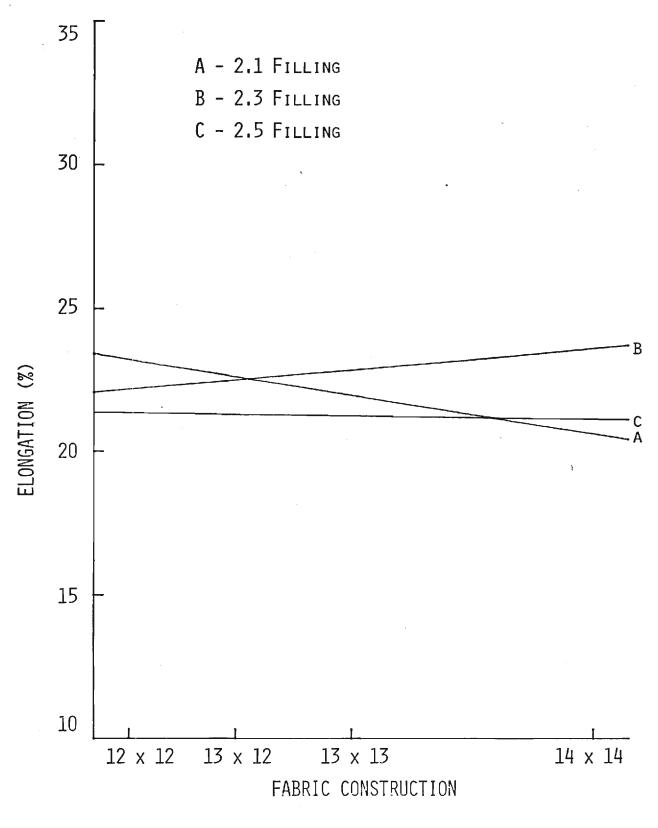


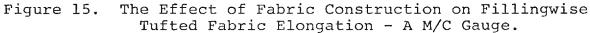


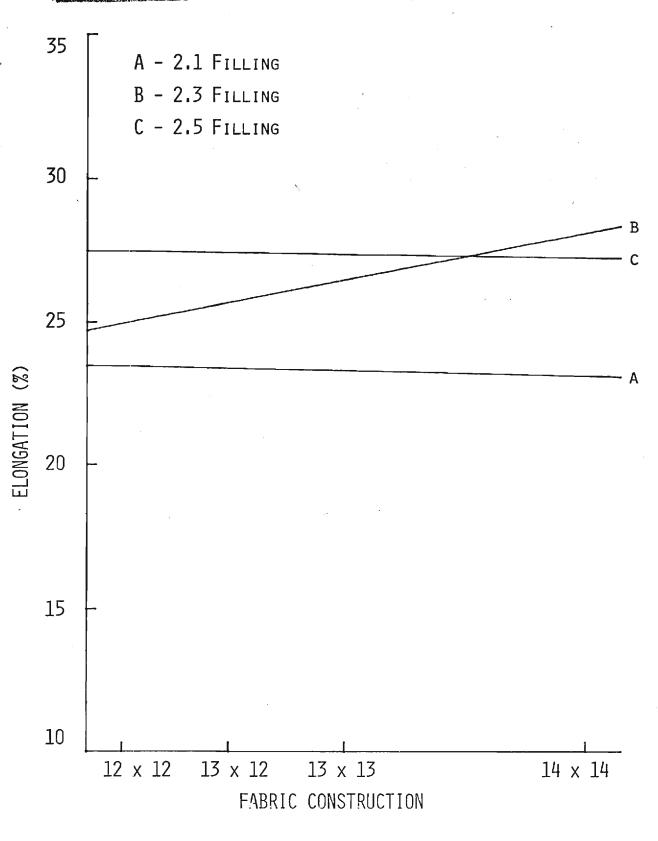


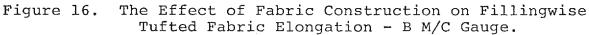












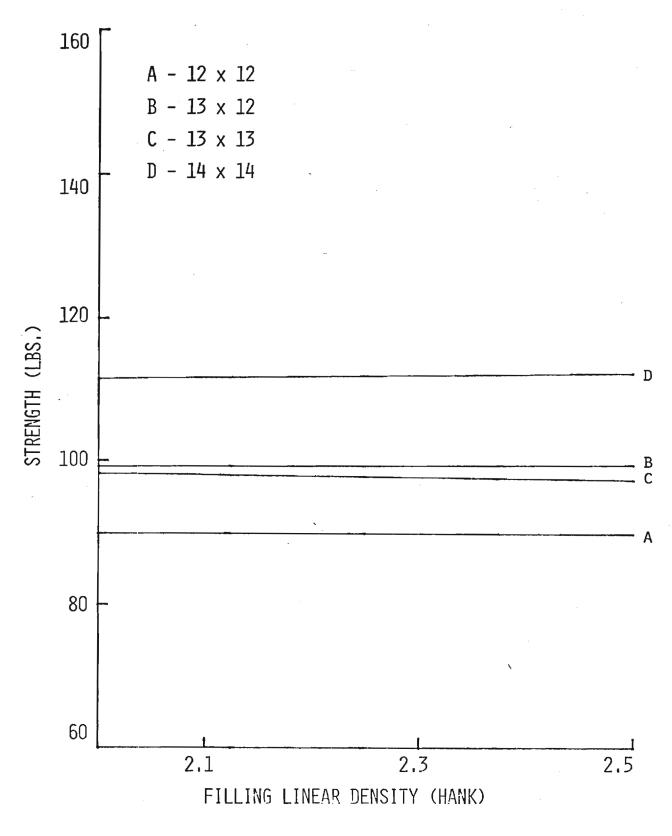
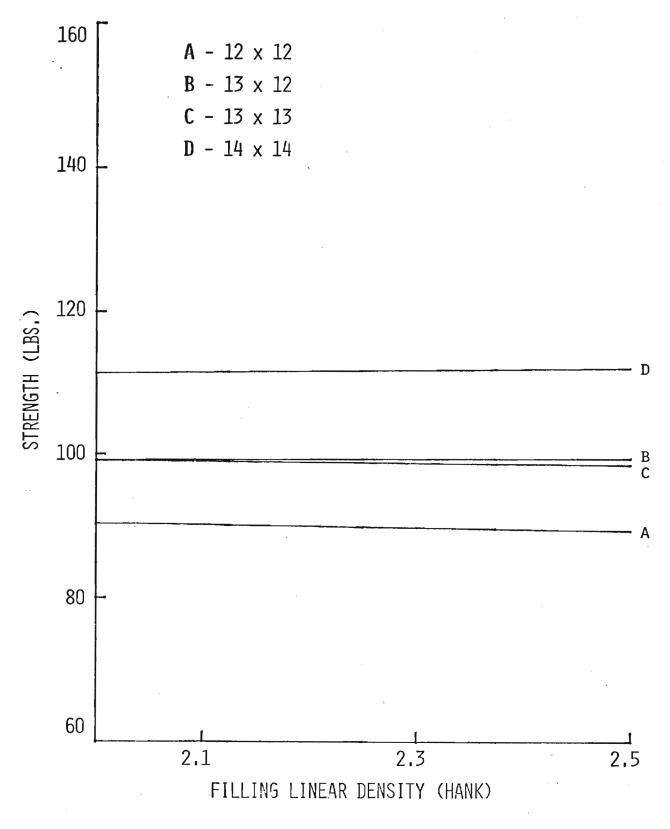
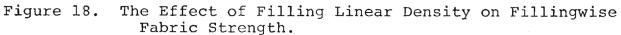
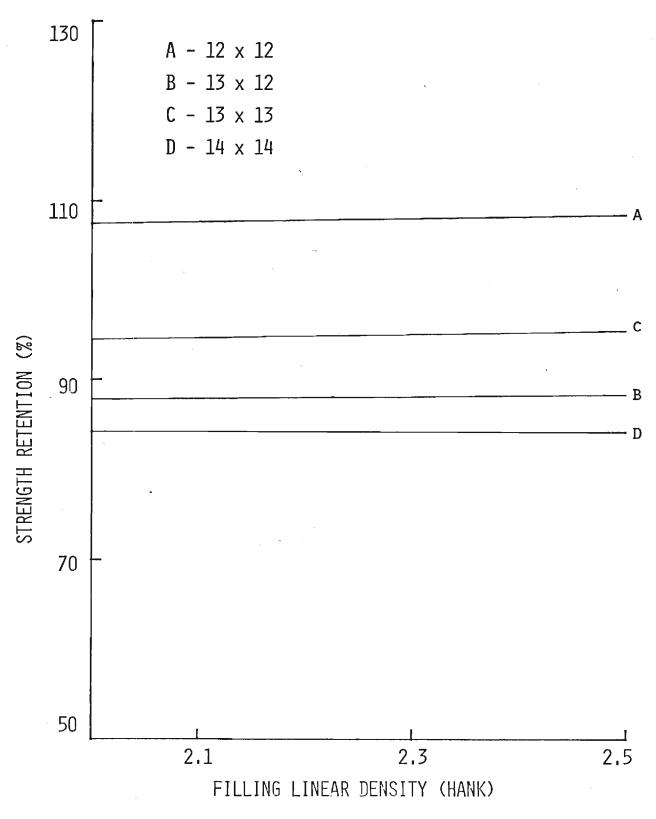
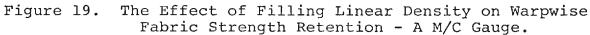


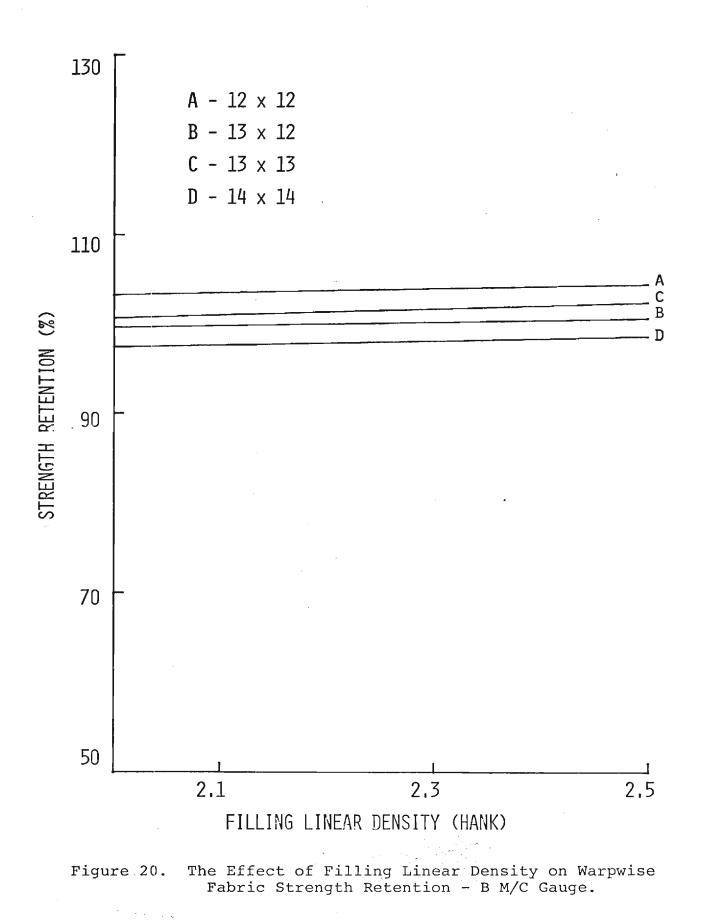
Figure 17. The Effect of Filling Linear Density on Warpwise Fabric Strength.

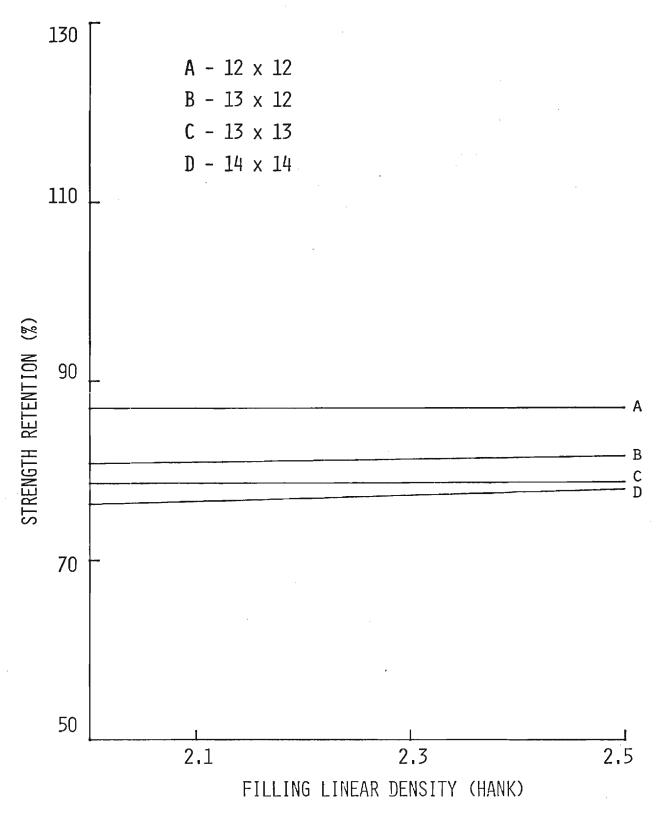


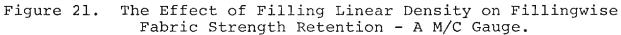


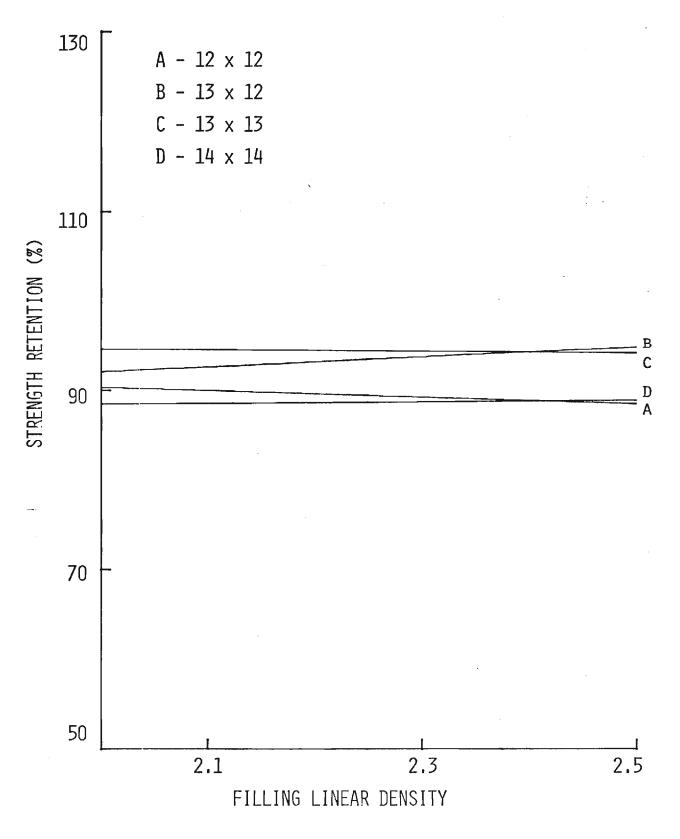


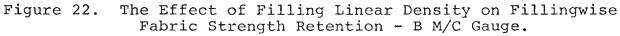












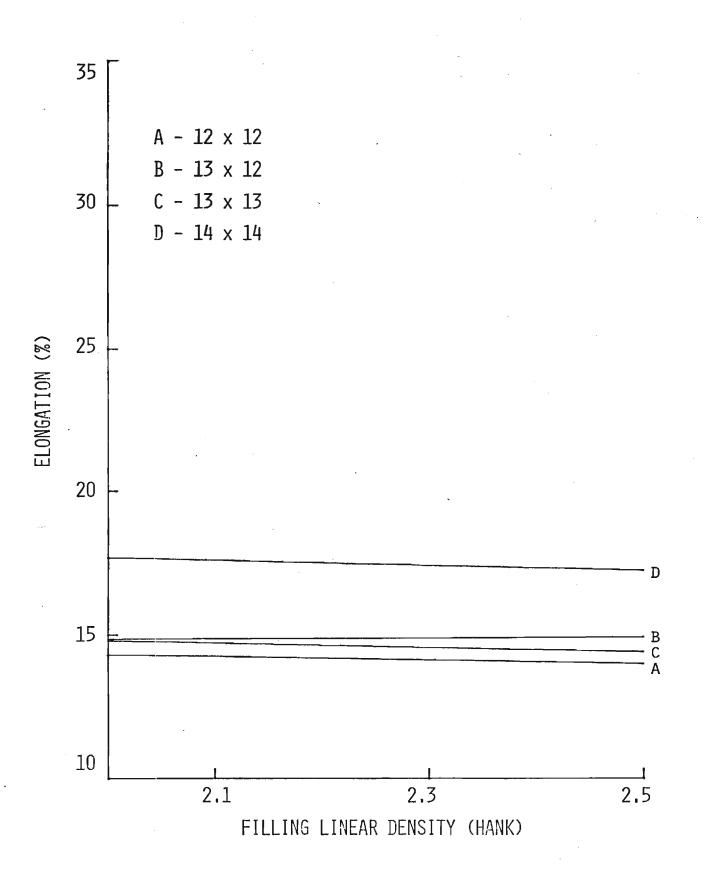


Figure 23. The Effect of Filling Linear Density on Warpwise Untufted Fabric Elongation.

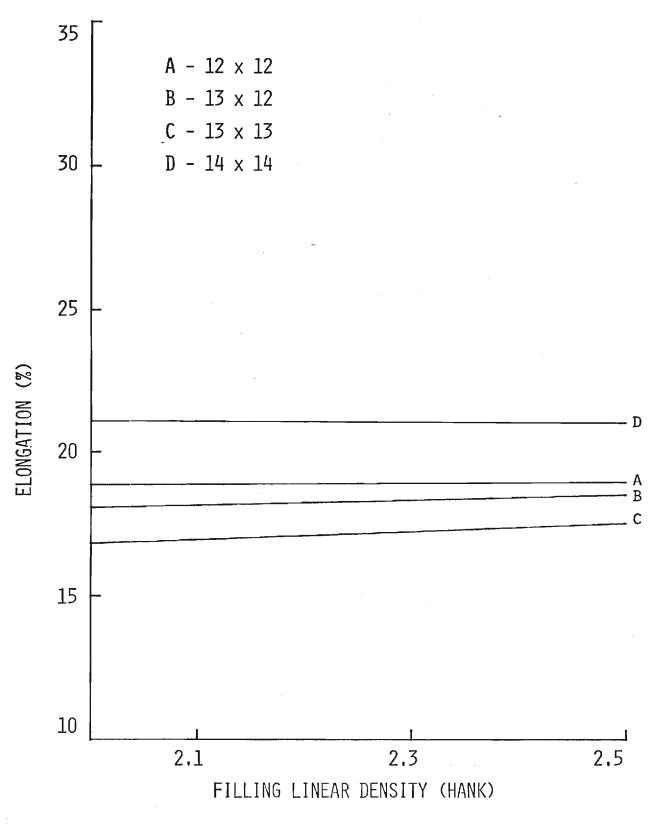
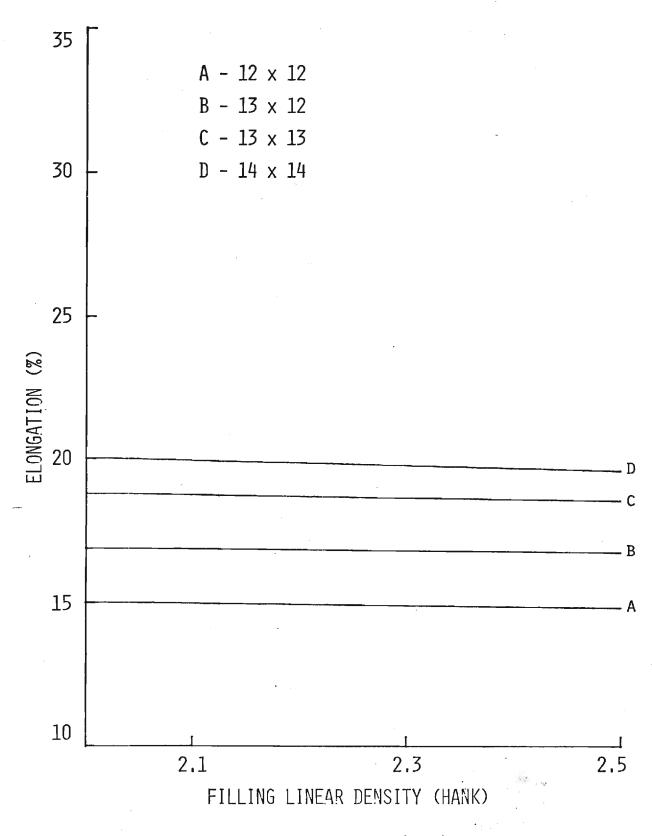
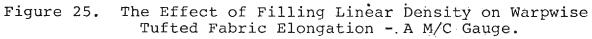
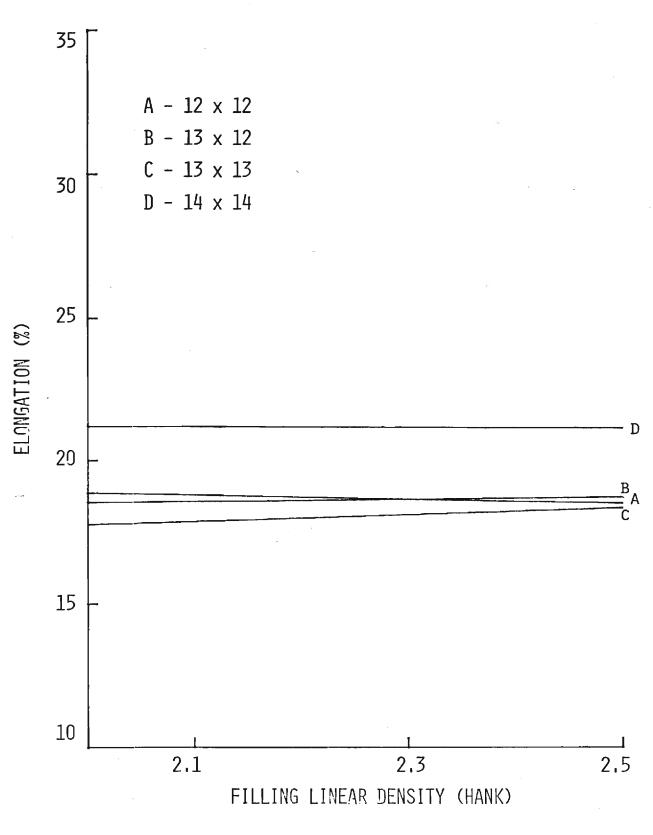
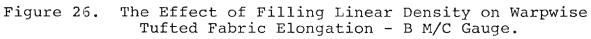


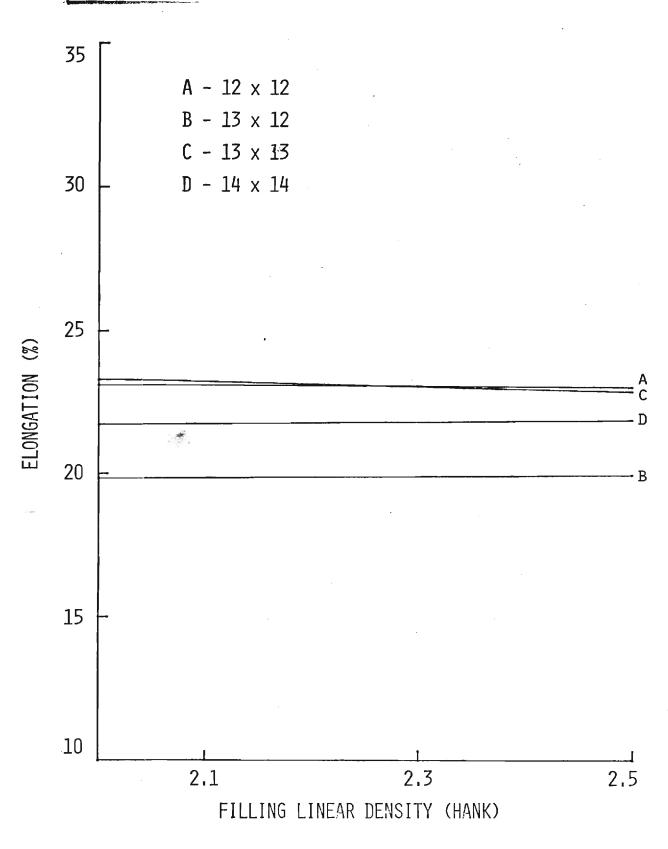
Figure 24. The Effect of Filling Linear Density on Fillingwise Untufted Fabric Elongation.

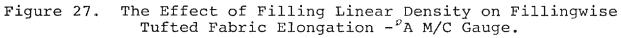


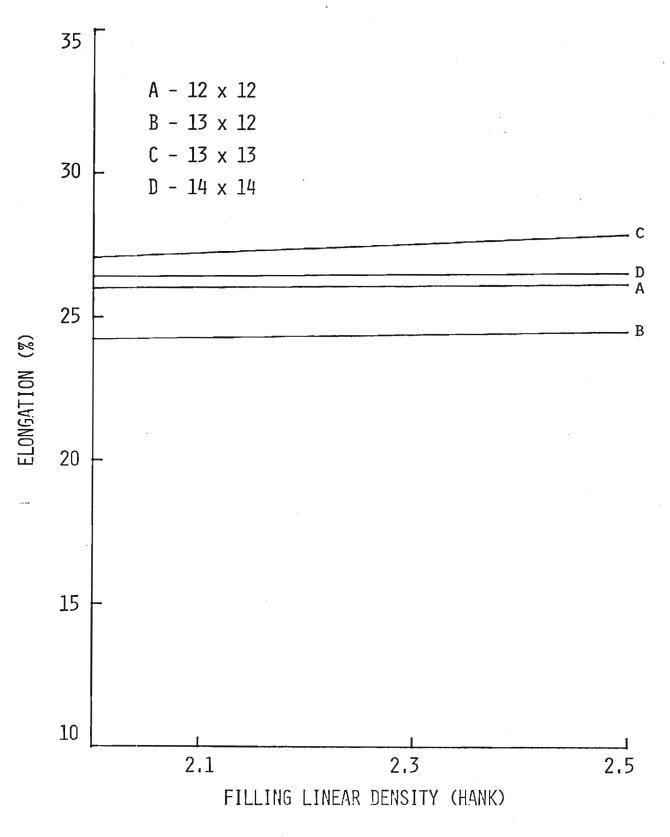


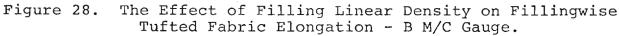


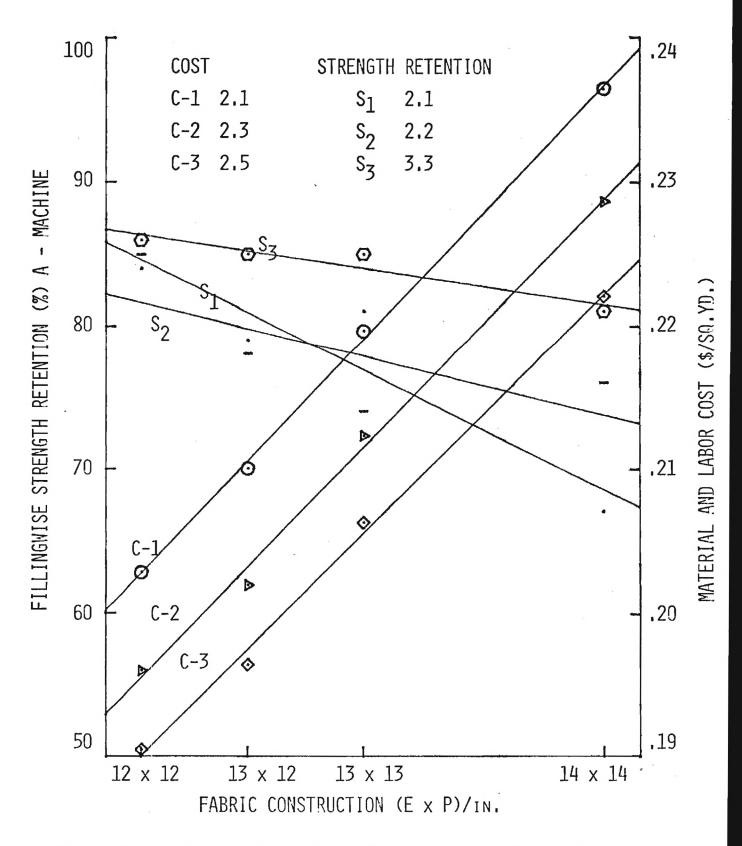


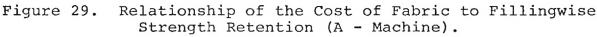


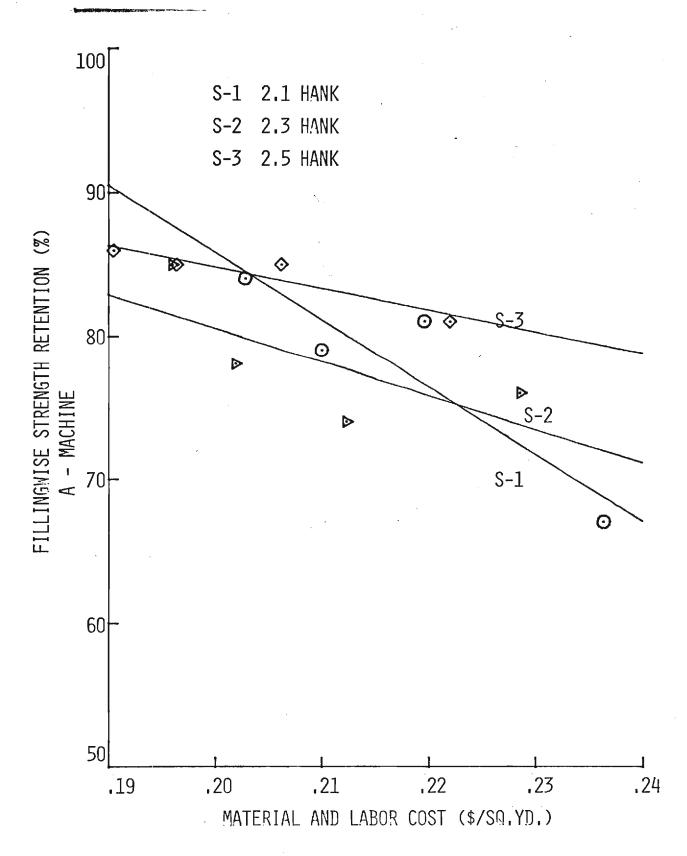


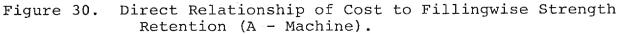












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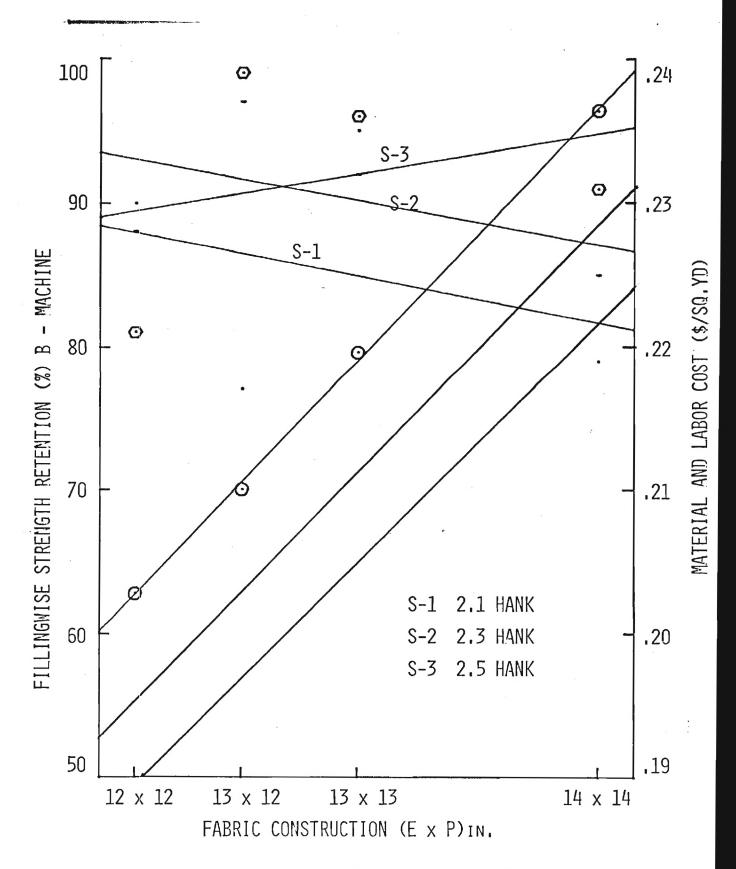


Figure 31. The Relationship of the Cost of Fabric to Fillingwise Strength Retention (B - Machine).

100 \diamond S-3 Ð \odot 0 D \Diamond 90 Ο FILLINGWISE STRENGTH RETENTION (%) B - MACHINE D S-2 S-1 80F Ο 0 70 2.1 HANK S-1 S-2 2.2 HANK 2.3 HANK S-3 60 50 .20 .21 .22 .23 ,19 .24 MATERIAL AND LABOR COST (\$/SQ.YD.)

Figure 32. Direct Relationship of Cost to Fillingwise Strength Retention (B - Machine).

APPENDIX II

COMPUTER PRINTOUTS

PRINTOUT I

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PRINTOUT II

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	VARIABLE ENTERED 1
	MULTIPLE R .7293
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	ANALYSIS OF VARIANCE
	DF SUM OF SQUARES MEAN SQUARE F RATIO REGRESSION 1 515-107 515-107 20-455
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•	(CONSTANT 102-01682) MC 1 -11+15546 2.29387 C 2 .29148 .06327 J 3 -28-61904 7.31181	23.6546 CD 4 21.2266 15.3201	• 36689	.1255	2,3332	
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•	STEP NUMBER 4 VARIABLE ENTERED 4				•	
•	MULTIPLE R .8965 STD. ERROR OF EST. 4.8668					
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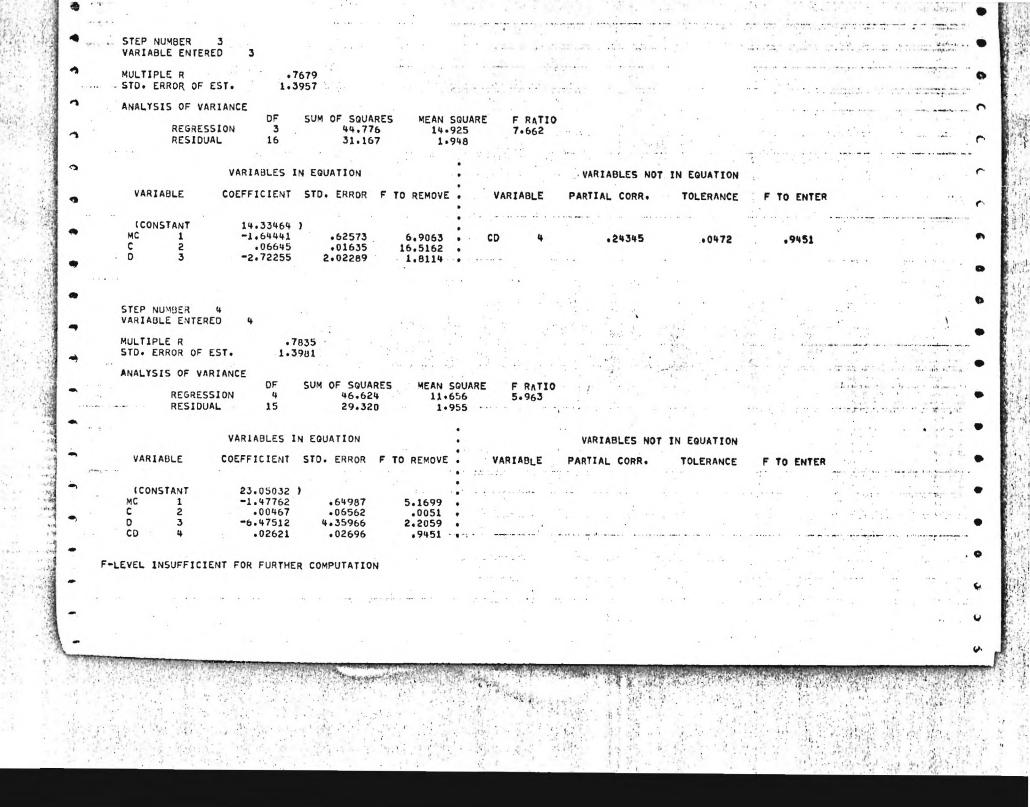
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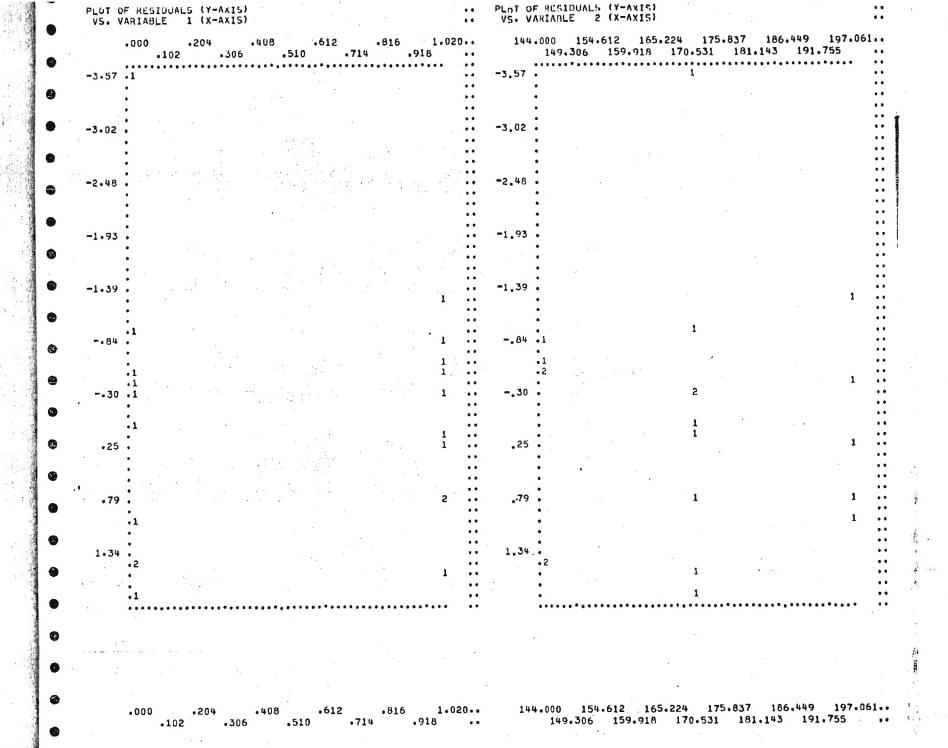
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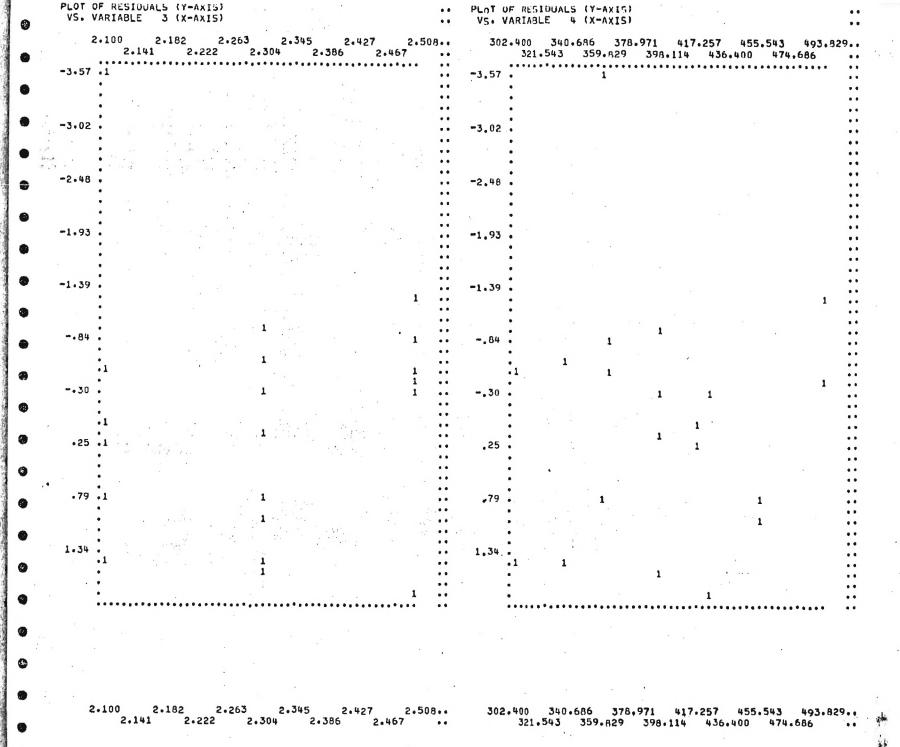
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SUMMARY TABL							
STEP NUMBER	ENTERED	REMOVED		E RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1 2	C 2 D 3		•5902 •7821	• 3484 • 6117	-3484	9.6229 11.5301	1
3	CD 4 MC 1		• 9116 • 8119	•6587 •6592	.3484 .2634 .0470 .0005	2.2024	2 3 4
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34	06220 -2.04070 -6.22570 1.62897					<u> </u>	
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7 8	1.55605 4.79413 3.15952 3.01591 -7.51264						
9 10 11	1,48736 15469				1		
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PRINTOUT VII

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-	(CONSTANT 88.70000)	12.5483	C 2 D 3	30035 .26948	TOLERANCE .9951 1.0000	1,5855	
	(CONSTANT 88.70000)	12.5483	<u>c 2</u>	30035	TOLERANCE	1,5855	
	(CONSTANT 88.70000)	12.5483	C 2 D 3	30035 .26948	TOLERANCE .9951 1.0000	1,5855	· · · · · · · · · · · · · · · · · · ·
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	(CONSTANT B8.70000) MC 1 -9.60000 2.71006 STEP NUMBER 2 VARIABLE ENTERED 2 MULTIPLE R .6811 STD. ERROR UF EST. 5.9477 AVALYSIS OF, VARIANCE 0F, SUM OF SQUARE: REGRESSION 2 520.429	12.54A3		30035 .26948	TOLERANCE .9951 1.0000	1,5855	
	(CONSTANT B8.70000) MC 1 -9.60000 2.71006 SIEP NUMBER 2 VARIABLE ENTERED 2 MULTIPLE R .6811 SID. ERROR UF EST. 5.9477 AVALYSIS OF, VARIANCE DF, SUM OF SQUARES	12.54A3	C 2 D 3 CD 4 F RATIO	30035 .26948	TOLERANCE .9951 1.0000	1,5855	
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	(CONSTANT B8.70000) MC 1 -9.60000 2.71006 SIEP NUMBER 2 VARIABLE ENTERED 2 MULTIPLE R .6811 SID. ERROR UF EST. 5.9477 AVALYSIS OF VARIANCE REGRESSION 2 520.429 RESIDUAL 17 601.370 VARIABLES IN EQUATION	12.54A3 	C 2 D 3 CD 4 F RAYIO 7.356	30035 .26948 18547	TOLERANCE .9951 1.0000 1.0000 I.0000	1,5895 1,3312 .6056	
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$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	STEP NUMBER	VARIABLE ENTERED REMOVED	MULTIF R	RS0	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDE VARIABLES INCLUDE
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	1 2 3 4	0 3	•6409 •6811 •7185 •7346	. 4639	.4108 .0532 .0523 .0234	1.7309	3
$\begin{array}{c c c c c c c c c c c c c c c c c c c $			ac fi	²			
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	LIST OF RE	SIDUALS			· · ·		
	$ \begin{array}{r} 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 8\\ 9\\ 10\\ 11\\ 12\\ 13\\ 14\\ 15\\ 16\\ 17\\ 18\\ 19\\ 19\\ 19\\ 19\\ 19\\ 19\\ 19\\ 19\\ 19\\ 19$	$\begin{array}{r} 3.1682\\ 4.7323\\65373\\ 3.52736\\ 4.13374\\ 3.55505\\5.15500\\7.15560\\2.80924\\12.63952\\ 3.20592\\76923\\1.61673\\3.43515\\3.43515\\3.43515\\3.435140\\3.8140\\3.8140\\3.8140\\$					

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LOT OF RESIDUALS (Y-AXIS) VS. VARTABLE 2 (Y-AXIS)		
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2 PLOT OF RESTU VS. VARIABLE	5 (X_4X15)	
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