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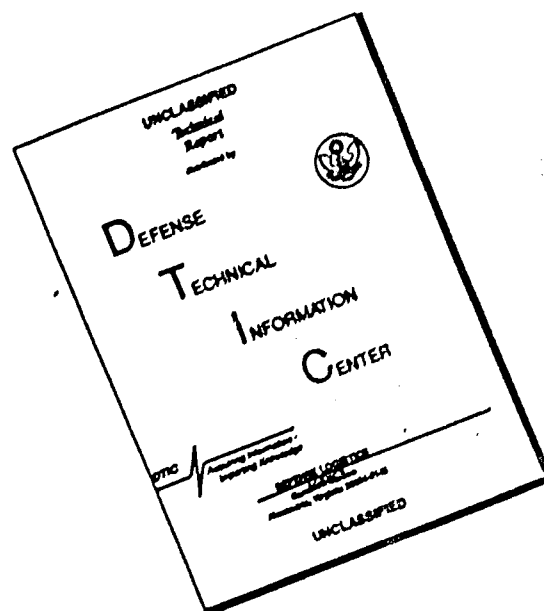
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STUDY OF THE CONTROL OF PERMEABILITY
OF NYLON PARACHUTE CLOTH
AT HIGH AND LOW DIFFERENTIAL PRESSURES

REPORT OF THE

NAVY AIR FORCE

RESEARCH AND DEVELOPMENT

NAVY AIR FORCE

NAVY AIR FORCE

NAVY AIR FORCE DEVELOPMENT CENTER

**STUDY OF THE CONTROL OF PERMEABILITY
OF NYLON PARACHUTE CLOTH
AT HIGH AND LOW DIFFERENTIAL PRESSURES**

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MARCH 1955

MATERIALS LABORATORY

CONTRACT No. AF 33(600)-26109

PROJECT No. 7320

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was prepared by the Cheney Brothers Company under USAF Contract No. AF 33(600)-26109. The contract was initiated under Project No. 7320, "Air Force Textile Materials", Task No. 73201, "Textiles Materials for Parachutes", formerly RDO No. 612-12, "Textiles for High Speed Parachutes", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Miss Joyce C. McGrath acting as project engineer.

The work reported herein covers the period from September 1953 to November 1954.

ABSTRACT

Twenty-four differently constructed samples of nylon cloth in the desired weight range were woven, finished and tested.

A special mathematical study of the relationship between air permeability at 1/2 inch of water pressure differential and at higher pressure differentials was made. This discloses that a linear relationship in these values exists when plotted on full logarithmic graph paper.

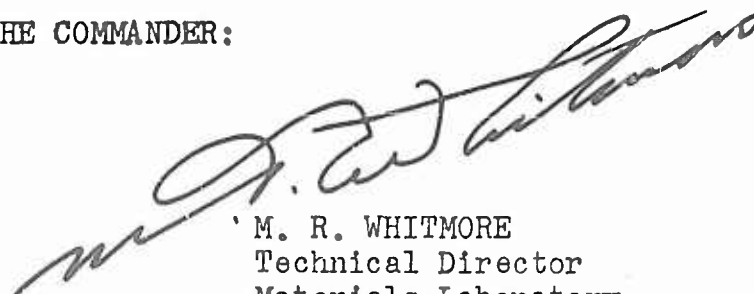
The ability of the cloth manufacturer to vary the high pressure differential permeability, while retaining fixed low pressure permeability ranges, is indicated to be a practical one within limits.

A total of 1000 yards of additional cloth duplicating two of the twenty-four constructions as selected by the Air Force was supplied for use in further evaluation of the material by the Parachute Branch of Equipment Laboratory.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:



M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
I. PROCEDURE.	2
A. WEAVING OF SAMPLES	4
B. FINISHING OF SAMPLES	4
C. FURNISHING CLOTH FOR PARACHUTE EVALUATION. . .	5
D. WEAVING OF REPRODUCTION LOTS	5
E. FINISHING OF REPRODUCTION LOTS	5
F. TESTING.	6
II. DISCUSSION	23
A. 1. Mathematical Relationships	23
2. Significance of "K".	29
3. Practical Use of "K" in Fabric Design. . .	32
4. "K" Value Correlation.	38
B. GENERAL COMMENTS	40
1. Weaving.	40
2. Finishing.	40
3. Permeability Adjustments	40
C. CONCLUSIONS.	41
APPENDIX I - MATHEMATICAL DEVELOPMENT.	42
APPENDIX II - METHODS OF DETERMINING "K"	44
APPENDIX III - BIBLIOGRAPHY.	46

LIST OF TABLES

<u>Table</u>		<u>Page</u>
I	PHYSICAL TESTS ON GREIGE CLOTH	8
II	PHYSICAL TESTS ON FINISHED CLOTH (Sample Lots) .	9
III	PHYSICAL TESTS ON FINISHED CLOTH - REPRODUCTION LOTS	12
IV	AIR PERMEABILITY - $\text{FT.}^3/\text{MIN.}/\text{FT.}^2$ - FINISHED CLOTH.	14
V	AIR PERMEABILITY ($\text{FT.}^3/\text{MIN.}/\text{FT.}^2$) OF 24 SAMPLES AT VARIOUS PRESSURE DIFFERENTIALS.	15
VI	AIR PERMEABILITY ($\text{FT.}^3/\text{MIN.}/\text{FT.}^2$) OF 24 PRODUCTION SAMPLES	16
VII	AIR PERMEABILITY - $\text{FT.}^3/\text{MIN.}/\text{FT.}^2$ - FINISHED CLOTH - REPRODUCTION LOTS.	21
VIII	FACTORS AFFECTING VALUE OF "K"	30
IX	Calculated Values of Air Permeability (Cu Ft/ Min/Sq Ft) at 20-In. Water Pressure Differential for Different Values of "K" . . .	35
X	"K" VALUE CORRELATION.	39

LIST OF GRAPHS

<u>Graph</u>		<u>Page</u>
1	WEAVE DIAGRAMS	3
2	AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1N-6N, DATA FROM TABLE VI.	17
3	AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7N-12N, DATA FROM TABLE VI	18
4	AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1C-6C, DATA FROM TABLE VI.	19
5	AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7C-12C, DATA FROM TABLE VI	20
6	AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, 1/2"-12", TESTS - REPRODUCTION LOTS R1C, R2C and R4C, DATA FROM TABLE VII	22
7	(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1N-6N, DATA FROM TABLE VI	24
8	(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7N-12N, DATA FROM TABLE VI	25
9	(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1C-6C, DATA FROM TABLE VI	26
10	(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7C-12C, DATA FROM TABLE VI	27
11	(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, 1/2"-12", TESTS - REPRODUCTION LOTS R1C, R2C and R4C, DATA FROM TABLE VII	28
12	"K" vs. PERMEABILITY AT 20-IN. PRESSURE DIFFERENTIAL FOR VARIOUS PERMEABILITY LEVELS AT 1/2-IN. PRESSURE.	36

INTRODUCTION

Relatively little data are available to indicate whether or not the air permeability characteristics at increased pressure differentials for a given construction of parachute fabric may be varied independently of the air permeability characteristics at the 1/2-inch pressure differential. If it is determined that a fabric manufacturer can control these properties independently, it may prove to be possible to develop a fabric which will provide the parachute designer with a selection of properties which will enable him to achieve improved parachute performance.

It is therefore the objective of this contract to obtain basic information as to how the permeabilities, at high and low pressures, of a given nylon fabric could be independently controlled.

SECTION I

PROCEDURE

For purposes of this study, one type of fabric was investigated, namely the fabric described by Specification MIL-C-7350, Type I, 2.25-oz. Nylon Cargo Parachute Fabric. Fabric to this specification has been used in certain cargo parachutes of large dimensions, such as the No. G-12. Under this experimental contract, 24 variations of the basic fabric were woven as follows:

Yarn: 100/34, Type 300, High Tenacity Nylon
Twist as noted below

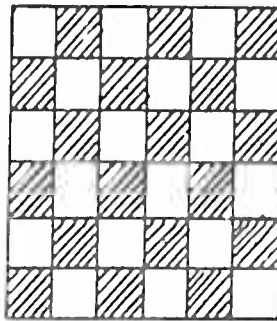
Warp: 64 Ends/inch, 42.2 inches wide - in reed

Filling: 68 Picks/inch off loom

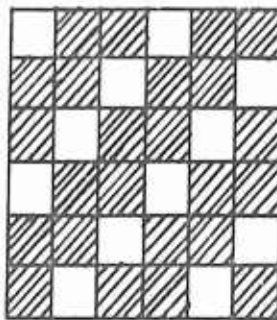
Code No.	Nominal Twist/ Inch (Z)		Weave	Finish		
	Warp	Filling				
1N	0.75	0.75	Plain	Not calendered		
2N	0.75	0.75	Twill(2x1)	"	"	"
3N	0.75	0.75	Dobby	"	"	"
4N	0.75	5.75	Plain	"	"	"
5N	0.75	5.75	Twill(2x1)	"	"	"
6N	0.75	5.75	Dobby	"	"	"
1C	0.75	0.75	Plain	Calendered in grey		
2C	0.75	0.75	Twill(2x1)	"	"	"
3C	0.75	0.75	Dobby	"	"	"
4C	0.75	5.75	Plain	"	"	"
5C	0.75	5.75	Twill(2x1)	"	"	"
6C	0.75	5.75	Dobby	"	"	"
7N	5.75	0.75	Plain	Not calendered		
8N	5.75	0.75	Twill(2x1)	"	"	"
9N	5.75	0.75	Dobby	"	"	"
10N	5.75	5.75	Plain	"	"	"
11N	5.75	5.75	Twill(2x1)	"	"	"
12N	5.75	5.75	Dobby	"	"	"
7C	5.75	0.75	Plain	Calendered in grey		
8C	5.75	0.75	Twill(2x1)	"	"	"
9C	5.75	0.75	Dobby	"	"	"
10C	5.75	5.75	Plain	"	"	"
11C	5.75	5.75	Twill(2x1)	"	"	"
12C	5.75	5.75	Dobby	"	"	"

Note: The dobby weave used is that shown in Specification MIL-C-7350, Type I, Weave Diagram (See Graph 1).

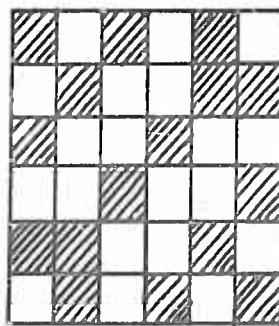
GRAPH 1
WEAVE DIAGRAMS



Plain Weave



2x1 Twill



Dobby

A. WEAVING OF SAMPLES

A 500-yard warp was made using the 100/34/.75-Z yarn and 40 yards each of Code Nos. 1 through 6 were woven in succession, this yardage to be finished as Code Nos. 1N through 6N. Another 40 yards each of Code Nos. 1 through 6 were then woven, to be finished as Code Nos. 1C through 6C.

A second 500-yard warp was made with the 100/34/5.75-Z yarn and 40 yards each of Code Nos. 7 through 12 were woven, to be finished as Code Nos. 7N through 12N. Another 40 yards each of Code Nos. 7 through 12 were then woven, to be finished as Code Nos. 7C through 12C.

B. FINISHING OF SAMPLES

The samples bearing the Code Nos. 1C through 12C were given a hot calendering in the grey, two nips, approximately seven tons pressure. A Van Vlaanderen calender with one steam heated steel roll and two wool-felt paper filled rolls was used.

Samples 1C through 12C were then sewn to samples 1N through 12N and processed in one lot as follows:

Jig scour, four ends at the boil

3.0 lbs. Naccanol NR (National Aniline &
Chemical Co.)

2.0 lbs. Caustic Flakes
1.0 lb. Tripolyphosphate

100 gallons of water

Rinse, in the jig, three ends at the boil

4.0 lbs. Boric Acid

100 gallons of water

Flat extraction on a vacuum extractor

Pad through a solution of one quart of "Coronyl"
oil (E. F. Drew & Co.) in ten gallons of
water and dry at 275-300°F. in the crepe
dryer.

Steam tenter to width.

C. FURNISHING CLOTH FOR PARACHUTE EVALUATION

After reviewing the results obtained on the 24 samples, the Materials Laboratory requested reproduction under Item VI of the contract as follows:

750 yards Code 4C (Reproduction Code No. R4C)
250 yards Code 2C (Reproduction Code No. R2C)

In addition, a Local Purchase Branch order, Contract AF-33(616)-3547, was issued for:

500 yards Code 1C (Reproduction Code No. R1C)
250 yards Code 4C (Reproduction Code No. R4C)

D. WEAVING OF REPRODUCTION LOTS

A 2100-yard warp of 100/34/.75-Z, Type 300, Nylon, corresponding to the one used to manufacture the samples identified as Code Nos. 1, 2, and 4, was made and woven out in approximately 260-yard grey pieces as follows:

Code R1C	520 yards
Code R2C	260 yards
Code R4C	1,112 yards

E. FINISHING OF REPRODUCTION LOTS

The 1892 yards of grey fabric were processed in one lot, including hot calendering in the grey, as outlined under "B. FINISHING OF SAMPLES."

The Code R1C fabric showed permeability results (TABLE VII) close to those obtained in the Wright Air Development Center Materials Laboratory tests shown in TABLE V.

The Code R2C fabric had a permeability in initial tests of 33.3 cu ft/min/sq ft at 1/2-inch pressure and 265 cu ft/min/sq ft at 12 inches of pressure, which was somewhat higher than the permeability previously reported in TABLE V (1/2-inch - 26.5; 12-inch - 228.9), so we were requested by the Materials Laboratory to reduce the 1/2-inch pressure permeability to 26 cu ft/min/sq ft. The cloth was again hot calendered and rope washed at 120°F in plain water and steam tented. The outcome was a permeability of 29.4 cu ft/min/sq ft at 1/2-inch pressure and 275 cu ft/min/sq ft at 12-inch pressure as shown in TABLE VII. The cloth was then shipped without further reprocessing.

The Code R4C fabric had an initial porosity of 44.6 cu ft/min/sq ft at 1/2-inch pressure and 312 cu ft/min/sq ft at 12-inch pressure, slightly below the results obtained on Code 4C sample, as shown in TABLE V (1/2-inch - 55; 12-inch - 385). In an effort to raise the permeability to the desired level, one piece from this lot was rope washed, relaxed, on a reel, but showed no apparent permeability change. The remainder of the lot was not rehandled. Permeability tests on two pieces from this lot are shown in TABLE VII.

Under Item VI of this contract, we shipped:

238-4/8	yards - Code R2C
804	yards - Code R4C
<u>1042-4/8</u>	yards

Against Contract AF-33(616)-3547, we shipped:

481-6/8	yards - Code R1C
250-7/8	yards - Code R4C
<u>732-5/8</u>	yards

F. TESTING

Physical and chemical tests on the samples were made in accordance with Specification MIL-C-7350A, Amendment 1, Type I fabric. These tests (as applicable) were performed on grey goods (See TABLE I) and on finished goods (See TABLE II).

Seam efficiency tests on the 24 samples are reported in TABLE II.

Physical and chemical tests on the reproduction lots are reported in TABLE III.

TABLE IV lists Cheney Brothers' permeability test results on the 24 samples, tested over a pressure range of 1/2 inch through 12 inches of water (limit of contractor's equipment - United States Testing Company air permeability tester on which we changed the sample area from 6 sq in. to 1 or 2 sq in. as required by permeability range of the sample. The manometer which measures pressure drop across the fabric was changed by using a "U" tube filled with water instead of the manometer supplied by the manufacturer, which read to only a 1-inch pressure drop.)

TABLE V lists Wright Air Development Center Materials Laboratory permeability figures over a pressure range of 1 to 20 inches for the same marked areas as tested by Cheney Brothers and reported in TABLE IV. These tests were made on the Wright Air Development Center Frazier high pressure differential permeability tester, which has a range of 1 to 20 inches of water on 1 sq in. of fabric.

The permeability figures given in TABLE VI are an average of five readings on each sample over the 1 to 20-inch range made by Wright Air Development Center. These tests were made on the 25-yard samples submitted of each of the 24 fabrics. All conclusions drawn from this work are based on these figures.

TABLE VII lists the permeability readings over the 1/2-inch to 12-inch range obtained by Cheney Brothers on the reproduction lots.

TABLE I
PHYSICAL TESTS ON GREIGE CLOTH

Code No.	Weave	Twist per Inch		Air Permeability (Ft. ³ /Min./Ft. ²)**	Width Inches	Thickness (Inches)	Thread Count (Thds./In.)	
		Warp	Nominal (Z) Fill.				Warp*	Fill.*
1N	Plain	3/4	3/4	85	40	.0049	68	68
2N	Twill	3/4	3/4	90	40-1/4	.0054	67	68
3N	Dobby	3/4	3/4	103	40-3/4	.0050	66	67
4N	Plain	3/4	5-3/4	161	40-1/8	.0053	67	68
5N	Twill	3/4	5-3/4	214	40-3/5	.0057	67	68
6N	Dobby	3/4	5-3/4	205	40-3/4	.0057	67	68
7N	Plain	5-3/4	3/4	92	39-3/4	.0053	68	68
8N	Twill	5-3/4	3/4	144	40	.0060	68	68
9N	Dobby	5-3/4	3/4	155	40-1/4	.0060	67	67
10N	Plain	5-3/4	5-3/4	200	39-3/8	.0058	68	68
11N	Twill	5-3/4	5-3/4	284	39-5/8	.0064	68	68
12N	Dobby	5-3/4	5-3/4	321	39-5/8	.0065	68	67
1C	Plain	3/4	3/4	79	40-3/8	.0047	67	68
2C	Twill	3/4	3/4	106	41	.0057	66	68
3C	Dobby	3/4	3/4	107	40-1/2	.0051	66	68
4C	Plain	3/4	5-3/4	169	40	.0052	68	68
5C	Twill	3/4	5-3/4	206	40-3/4	.0060	66	68
6C	Dobby	3/4	5-3/4	204	40-3/8	.0058	67	67
7C	Plain	5-3/4	3/4	124	39-1/2	.0053	68	68
8C	Twill	5-3/4	3/4	143	40-1/4	.0060	67	67
9C	Dobby	5-3/4	3/4	140	40-1/4	.0061	67	68
10C	Plain	5-3/4	5-3/4	212	39-1/4	.0057	68	68
11C	Twill	5-3/4	5-3/4	290	39-1/2	.0066	68	68
12C	Dobby	5-3/4	5-3/4	282	40	.0064	68	67

*Nominal Thread Count, 68 x 68 on all samples.

**1/2" H₂O Dif.

TABLE II

PHYSICAL TESTS ON FINISHED CLOTH
(Sample Lots)

Code No.	Weave	Actual Twist/Inch (Z)		Width Inches	Thread Count (Thds./In.)		Weight (Ozs./Sq.Yd.)	Strip Breaking Strength (Lbs./In.)		Elongation %		Tongue Tearing Strength (Lbs.)	
		Warp	Fill.		Warp	Fill.		Warp	Fill.	Warp	Fill.	Warp	Fill.
1-N	Plain	.9	1.2	37-1/8	73	73	2.10	106.4	105.8	27	33	13.1	13.9
2-N	Twill	.8	1.2	37-1/2	72	71	2.02	107.8	107.0	27	34	18.4	16.5
3-N	Dobby	.9	.9	37-1/4	72	71	2.02	109.0	105.0	31	35	16.9	16.8
4-N	Plain	.8	6.0	37	73	73	2.05	106.0	106.6	30	34	13.6	13.3
5-N	Twill	.8	5.9	37-1/8	72	71	2.00	107.2	106.0	28	36	18.0	16.7
6-N	Dobby	.9	6.2	37-1/8	73	72	2.01	109.0	107.0	32	35	15.8	16.9
7-N	Plain	6.0	1.3	36-3/8	74	70	2.08	110.0	102.6	27	37	12.8	12.8
8-N	Twill	6.0	1.1	37-1/8	73	72	2.03	108.2	105.0	30	36	18.6	17.2
9-N	Dobby	6.3	1.2	36-1/2	74	71	2.02	110.6	104.4	28	36	16.3	16.3
10-N	Plain	6.0	6.5	36-1/8	74	71	2.10	110.4	103.0	28	39	12.2	13.7
11-N	Twill	6.3	6.5	36-1/2	74	71	2.06	110.0	105.0	28	38	18.3	17.4
12-N	Dobby	6.2	6.2	36-1/4	74	71	2.08	109.2	103.2	30	39	15.6	16.6
1-C	Plain	1.2	1.2	36-7/8	73	72	2.10	107.0	101.6	28	35	12.8	12.7
2-C	Twill	.7	1.2	37-1/2	72	72	2.02	109.0	100.0	30	33	19.0	15.2
3-C	Dobby	.8	1.3	37-1/4	72	71	2.01	107.2	103.0	33	39	16.2	15.4
4-C	Plain	1.0	6.7	36-7/8	73	72	2.16	109.0	108.6	27	35	13.6	13.5
5-C	Twill	.7	6.2	37	73	71	2.10	108.2	103.8	30	34	16.7	17.7
6-C	Dobby	.8	6.5	37	73	72	2.02	108.6	106.0	31	34	16.6	17.0
7-C	Plain	5.8	1.3	36-1/2	74	72	2.16	109.4	103.0	31	37	13.5	12.8
8-C	Twill	6.3	1.4	36-3/4	73	71	2.04	113.2	107.0	29	36	19.5	17.1
9-C	Dobby	6.0	1.2	36-3/4	73	72	2.03	108.8	101.0	31	35	17.7	17.3
10-C	Plain	6.2	6.4	36-1/8	75	72	2.16	110.0	103.6	30	37	12.3	13.5
11-C	Twill	6.0	6.5	36-1/2	74	72	2.04	112.2	107.4	29	37	19.6	17.8
12-C	Dobby	6.2	6.5	36-1/2	74	70	2.08	112.4	103.2	29	37	16.4	16.7

TABLE II continued

PHYSICAL TESTS ON FINISHED CLOTH
(Sample Lots)

SEAM EFFICIENCY TESTS (Average of 5 Tests)

Code No.	Tensile Lbs. (Grab Method)		Seam Efficiency - %
	Cloth	Seam	
1M	138.4	99.2	71.8
2M	133.8	112.4	84.0
3M	138.0	98.4	71.4
4M	138.8	97.0	69.8
5M	131.2	94.8	72.2
6M	135.8	103.2	76.0
7M	142.2	100.8	70.8
8M	131.8	91.4	69.2
9M	132.6	97.6	73.8
10M	137.2	82.8	60.2
11M	140.4	84.8	60.6
12M	127.4	91.0	71.4
4C	143.2	97.0	67.6
2C	129.2	109.4	84.6
3C	133.6	102.6	76.6
4C	142.6	94.4	66.2
5C	130.4	95.2	73.0
6C	140.8	94.0	66.4
7C	146.0	96.8	66.4
8C	130.8	99.2	75.8
9C	137.4	99.6	72.6
10C	130.0	92.0	70.8
11C	131.4	85.0	64.8
12C	130.2	97.6	75.0

Method 5110 of CCC-T-191b, except seams were made using standard nylon cargo seam; 10 stitches per inch, 2-needle machine, "E" nylon sewing thread. Samples were sewed with two selvages in seam.

TABLE III

PHYSICAL TESTS ON FINISHED CLOTHREPRODUCTION LOTS

Code No.	Weave	Actual Twist/Inch (2)		Width- Inches		Thread Count (Thds./In.)		Weight (Ozs./ Sq.Yd.)		Strip Breaking Strength (Lbs./In.)		Elongation %		Tongue Tearing Strength (Lbs.)	
		Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.	Warp	Fill.
R1C	Plain	0.55	1.3	37-1/4		72	71	2.07		105.0	103.4	29	31	12.8	14.0
R2C	Twill	0.72	1.15	37-1/2		72	72	2.02		103.0	101.2	31	32	18.3	16.6
R4C Pc.#392647	Plain	0.65	7.0	36-3/4		73	71	2.08		108.0	97.8	30	34	12.2	12.6
R4C Pc.#392648	Plain	0.65	6.9	36-3/4		73	71	2.08		104.6	98.2	29	32	13.0	13.1

TABLE III (continued)

PHYSICAL TESTS ON FINISHED CLOTH

REPRODUCTION LOTS

Code No.	Thick- ness (Inches)	Seam Slippage (lbs.)		Permanence of Finish (% Change)			Extract- able Matter (%)	pH of Water Extract
		Warp	1/2" Separation Fill.	Thick- ness	Permea- bility	Shrinkage Warp Fill.		
R1C	.0049	67.4	79.9	+ 2.1	- 24.5	1.3 0.9	0.494	7.3
E2C	.0049	39.0	71.3	0	- 1.0	1.6 0.6	0.332	7.3
R4C Pc. #392647	.0050	70.5	75.3	0	- 5.8	1.3 0.4	0.46	7.1
R4C Pc. #392648	.0052	74.0	77.2	0	- 6.6	1.4 0.7	0.452	7.1

TABLE IV
AIR PERMEABILITY - $\text{FT.}^3/\text{MIN.}/\text{FT.}^2$ - FINISHED CLOTH

Pressure Differential Across Fabric - Inches H_2O :	1/2"	1"	2"	4"	6"	8"	10"	12"
Code No.								
1-N	33	56	89	138	176	213	243	273
2-N	41	72	111	177	233	282	324	363
3-N	53	81	141	209	258	318	366	408
4-N	104	166	256	361	456	534	609	681
5-N	143	231	332	510	648	762	870	966
6-N	127	200	297	435	555	657	759	855
7-N	35	63	97	163	219	270	312	351
8-N	68	119	194	288	372	452	516	576
9-N	83	140	223	333	430	510	594	669
10-N	130	207	308	475	618	738	846	936
11-N*	173	282	419	642	816	972	1116	1260
12-N*	199	301	450	696	900	1052	1188	1332
1-C	9	15	25	46	65	79	94	113
2-C	22	38	69	118	140	178	207	234
3-C	24	38	70	117	147	177	208	231
4-C	56	85	133	204	261	321	372	414
5-C	67	110	164	272	366	462	531	615
6-C	68	107	166	258	336	411	468	526
7-C	18	32	59	102	133	164	201	216
8-C	48	80	140	211	285	336	393	441
9-C	52	81	142	216	279	336	393	435
10-C	68	110	172	267	354	435	498	561
11-C	95	161	250	378	510	609	705	810
12-C	136	210	321	501	639	774	900	1044

*Area of sample, 1 Sq. inch. All other samples were tested using 2 sq. inch area.
Tests made by Cheney Brothers' Laboratory; U. S. Testing Co. permeability tester.
All Readings on Each Sample Made on One Marked Area Only, and
Without Disturbing Sample in Machine Until Series Completed.

TABLE V

AIR PERMEABILITY (FT.³/MIN./FT.²) OF 24 SAMPLES AT VARIOUS PRESSURE DIFFERENTIALS

Pres. Dif. Across Fab.													
Ins. H ₂ O:													
	1/2"	1"	2"	4"	6"	8"	10"	12"	15"	18"	20"	K	
Code No.													
1N	34.	53.02	84.13	132.2	170.4	200.9	235.8	267.	306.1	344.8	370.	.645	
2N	52.	75.5	123.6	196.	263.	296.3	346.2	386.75	442.	487.	520.2	.619	
3N	57.	86.62	135.8	207.	267.	317.2	364.	408.	467.2	522.4	556.8	.619	
4N	97.	152.1	221.4	335.2	424.6	502.6	575.	629.8	716.	793.8	847.	.576	
5N	138.	194.8	302.4	455.2	575.3	679.5	774.8	863.8	982.8	1089.	1151.7	.582	
6N	118.	170.4	267.	402.4	509.4	606.6	695.4	774.8	880.6	982.8	1050.	.602	
7N	38.	57.9	96.16	155.6	200.9	245.4	283.	319.05	370.	413.6	444.1	.662	
8N	77.	114.6	180.4	275.	354.4	422.	480.6	534.2	612.4	679.5	726.	.611	
9N	91.	138.6	221.	340.7	446.25	531.	612.4	684.8	781.85	872.2	931.	.634	
10N	120.	179.55	279.	432.4	545.4	651.4	747.4	828.4	946.	1057.35	1129.95	.610	
11N	154.	233.6	364.	569.	731.2	868.9	994.3	1111.8	1277.3	1433.5	1523.1	.625	
12N	172.	259.	408.	609.	796.	939.1	1075.5	1191.5	1371.5	1532.	1631.4	.611	
1C	9.	16.53	24.5	43.14	59.12	75.11	89.11	101.92	121.4	139.5	151.1	.759	
2C	26.5	40.3	68.08	110.9	145.	175.	202.6	228.9	259.	291.	309.8	.656	
3C	31.5	47.09	77.84	125.6	161.25	194.8	223.8	252.6	291.	324.6	348.	.647	
4C	55.	82.27	127.2	198.2	250.2	298.7	344.8	385.	442.8	498.2	531.2	.621	
5C	60.	87.69	141.8	229.8	296.3	357.35	408.	459.	531.	595.	641.4	.659	
6C	60.	92.46	145.	229.8	296.3	357.35	408.	459.	527.4	591.25	635.6	.642	
7C	24.	37.67	65.02	110.9	153.15	176.5	211.8	247.8	277.	313.5	338.8	.710	
8C	62.	92.46	154.8	249.	318.5	386.75	446.25	502.2	575.8	647.2	690.1	.648	
9C	60.	87.69	143.4	228.9	296.3	351.8	408.	459.	527.4	588.6	632.7	.640	
10C	62.	94.52	152.	246.	312.95	382.5	442.	495.	572.6	647.2	690.1	.661	
11C	95.	147.8	238.	374.	484.	585.2	674.2	763.05	880.6	990.2	1057.5	.654	
12C	109.	182.6	244.2**	337.6**	556.	672.6	771.7	860.8	980.6	1099.7	1179.8	.622	

*Values shown are extrapolations of logarithmic curves. 1/2" Readings not taken at WADC.

**Accuracy of test results doubtful.

***See Section II

Air Permeability Readings Made on WADC Frazier 20" H₂O Machine
(Single readings in same marked areas as for Table IV)

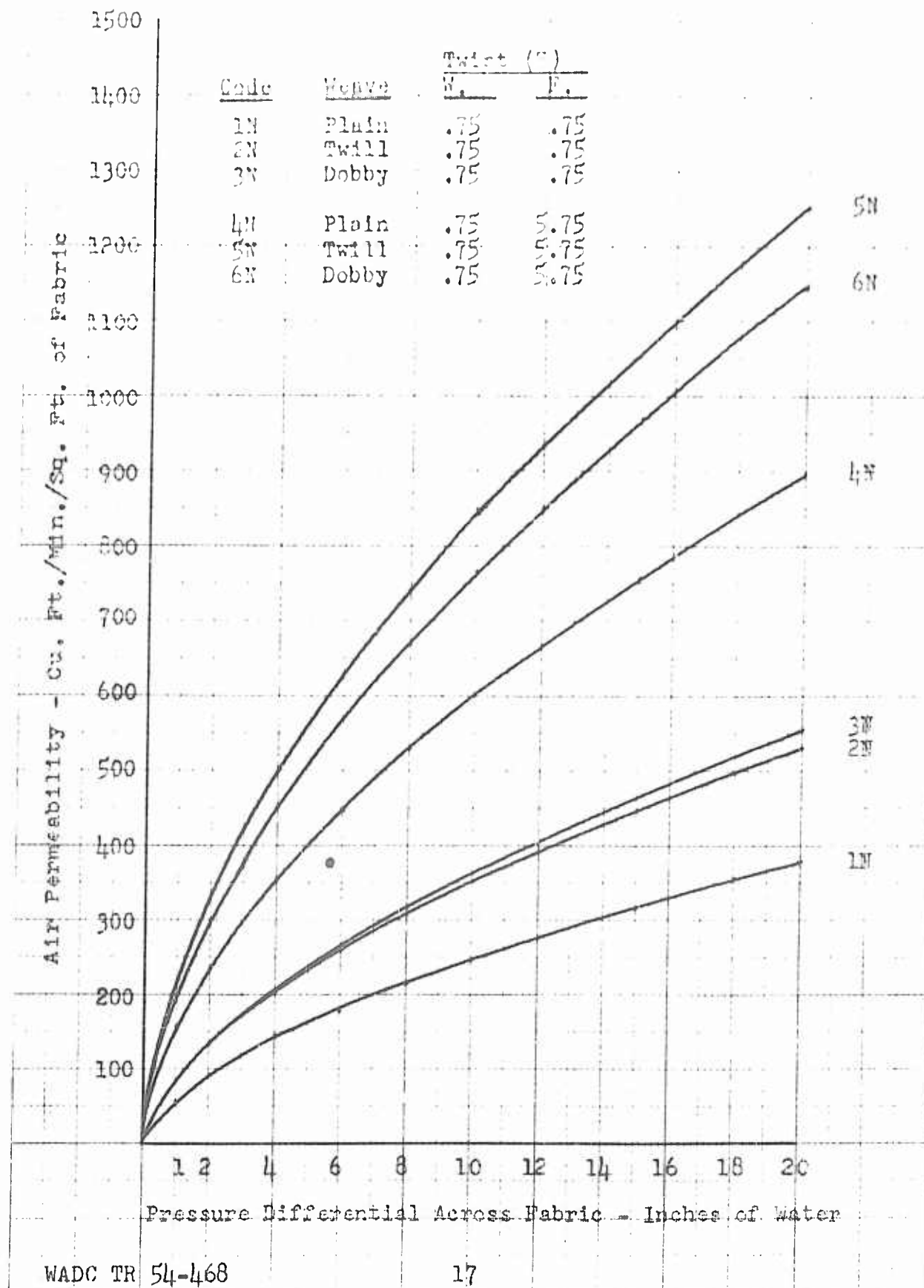
TABLE VI
AIR PERMEABILITY (FT.³/MIN./FT.²) OF 24 PRODUCTION SAMPLES

Pres. Dif. Across Fab. Ins. H ₂ O	1"	2"	4"	6"	8"	10"	12"	15"	18"	20"	K _{av} *
Code No.											
1N	57.3	91.1	143.9	178.3	214.4	245.3	273.8	316.8	354.9	379.2	.624
2N	80.9	132.2	200.6	258.7	308.6	352.4	393.1	448.2	498.8	531.2	.605
3N	86.6	137.2	207.2	265.9	317.2	363.9	406.3	465.3	518.9	553.2	.615
4N	157.6	238.2	357.2	446.7	529.0	601.1	669.3	759.9	844.5	898.2	.579
5N	219.5	335.8	505.1	632.3	744.8	843.9	936.7	1058.1	1178.4	1252.9	.575
6N	199.5	300.9	455.8	570.8	668.8	768.4	854.3	970.8	1077.9	1147.7	.582
7N	61.4	102.9	163.7	215.5	260.2	301.9	341.1	393.6	444.4	474.9	.665
8N	128.2	211.3	312.9	399.2	475.5	543.5	606.8	691.8	769.8	815.5	.609
9N	158.2	244.8	378.3	483.0	567.7	651.4	724.8	828.4	919.8	1032.4	.613
10N	192.9	299.3	458.9	572.9	685.3	783.2	889.7	999.1	1117.5	1189.3	.605
11N	290.4	432.2	657.6	836.9	988.8	1132.1	1254.9	1432.6	1595.8	1700.8	.591
12N	294.1	452.5	682.7	861.9	1021.2	1161.4	1292.5	1475.8	1640.4	1743.9	.591
1C	16.4	29.6	51.6	69.5	85.8	100.7	114.9	134.1	153.0	164.6	.740
2C	43.6	74.3	122.8	159.2	189.3	219.2	246.3	290.1	313.5	333.9	.663
3C	42.7	71.1	115.6	150.8	178.3	207.4	231.5	266.8	297.8	318.7	.645
4C	82.0	127.6	196.9	249.9	298.3	343.8	386.0	440.0	499.4	533.7	.622
5C	117.1	187.2	289.3	377.9	456.2	526.8	598.3	695.1	788.5	849.8	.658
6C	106.5	167.2	264.2	332.8	402.9	455.6	525.9	607.5	685.1	740.1	.643
7C	40.3	69.4	115.4	151.9	180.8	210.5	238.7	277.0	312.7	336.0	.679
8C	88.8	145.1	226.1	283.0	335.1	385.9	427.6	487.1	543.6	577.6	.597
9C	91.8	145.9	229.0	291.9	347.4	398.4	445.2	509.4	566.8	607.7	.626
10C	105.7	172.4	274.0	347.9	423.9	490.7	553.9	640.3	723.6	778.4	.660
11C	160.6	259.7	407.4	539.9	640.8	740.9	834.9	961.2	1083.9	1170.4	.658
12C	213.2	331.9	510.9	643.0	771.7	886.4	993.8	1142.9	1285.4	1372.6	.618

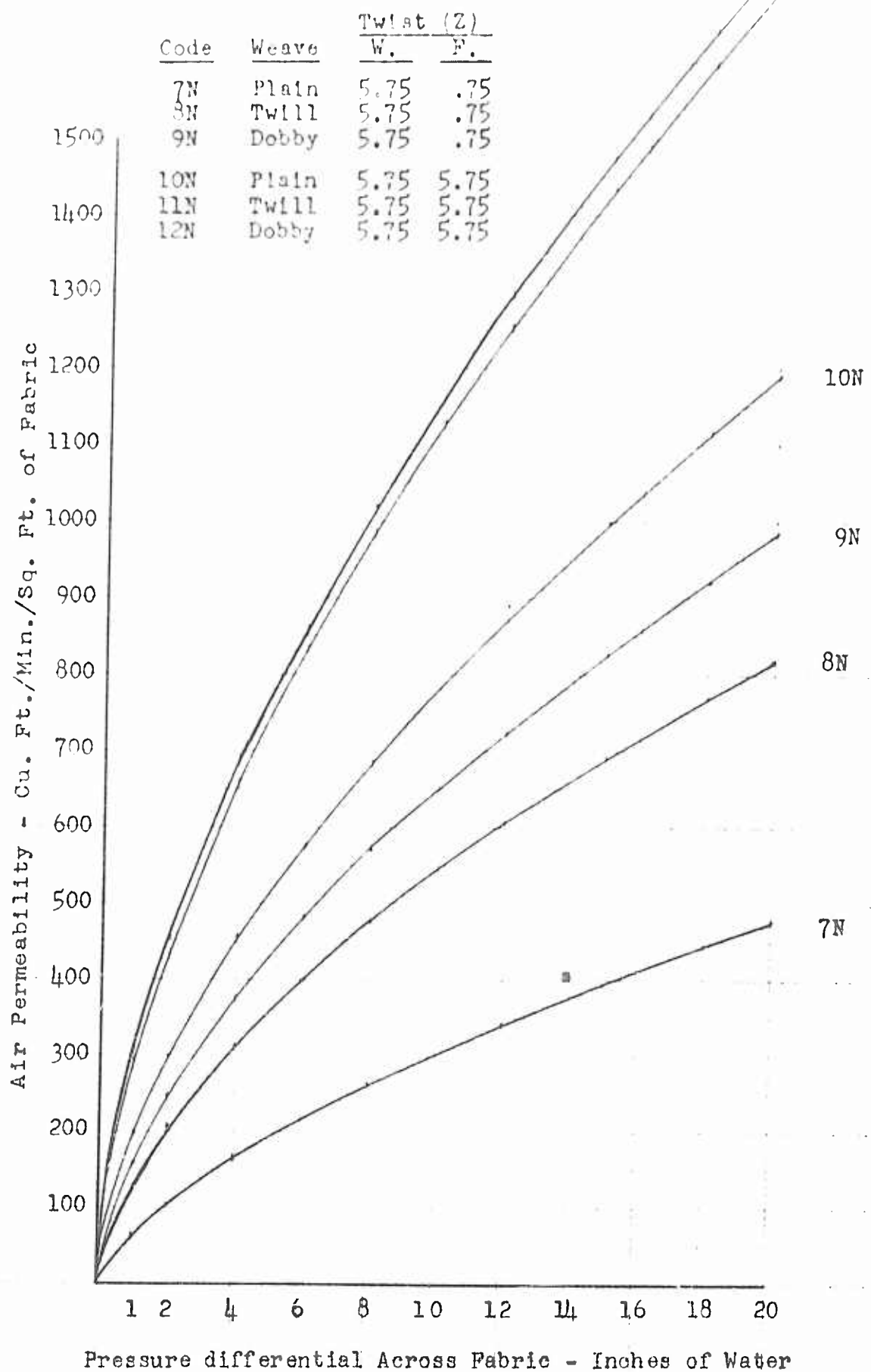
Note: As reported, WADC letter to Cheney Brothers, May 11, 1954. (Average of 5 readings each.)
*See Section II.

Air Permeability Readings Made on WADC Frazier 20" H₂O Machine.
(Average of 5 Readings Each)

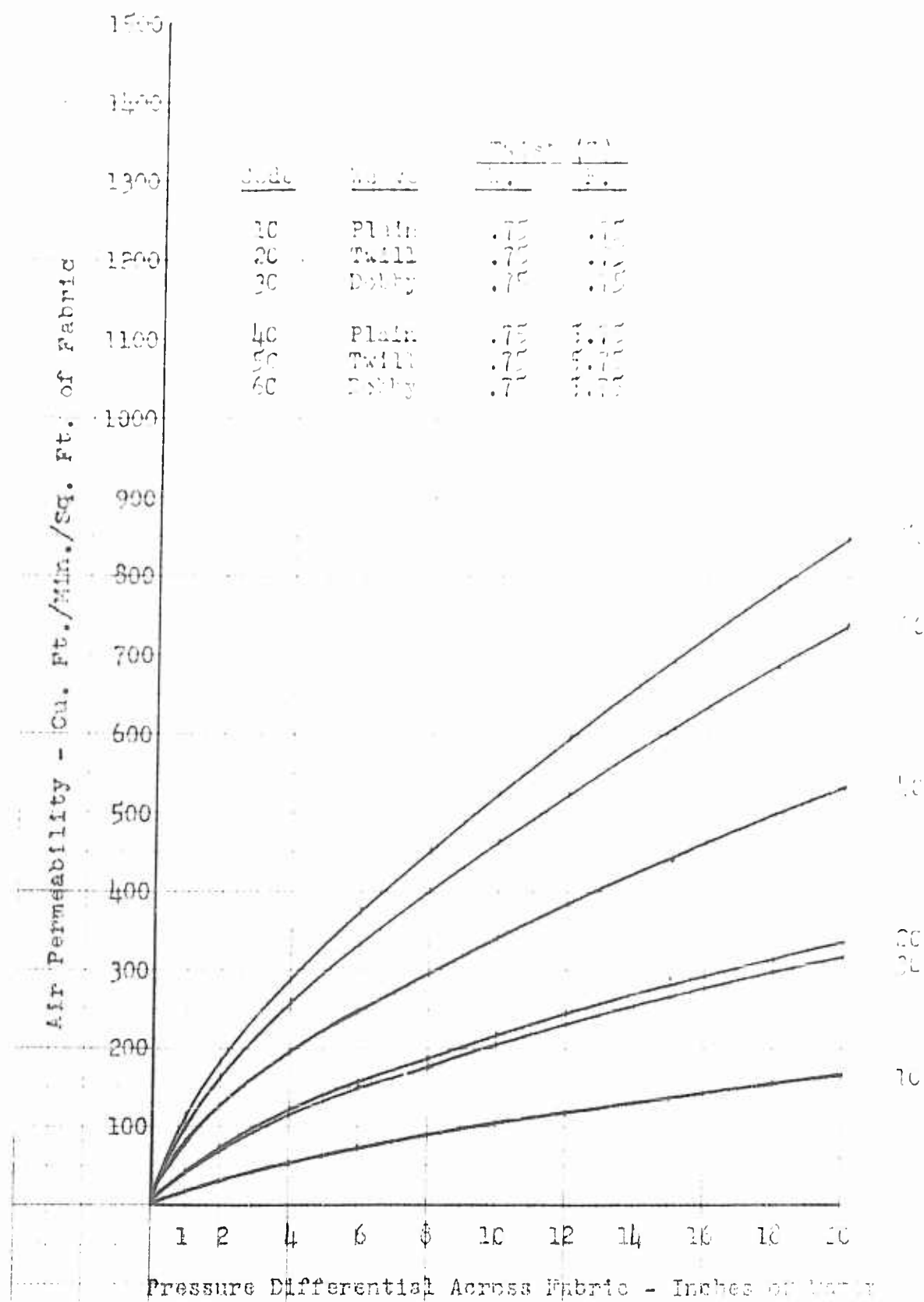
GRAPH 2
AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1N-6N
DATA FROM TABLE VI
(See also GRAPH 7)



GRAPH 3
AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7N-12N
DATA FROM TABLE VI
(See also GRAPH 2)



GRAPH 1.
AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 10-60
DATA FROM TABLE VI
(See also GRAPH 2)



GRAPH 5
AIF PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7C-12C
DATA FROM TABLE VI
(See also GRAPH 10)

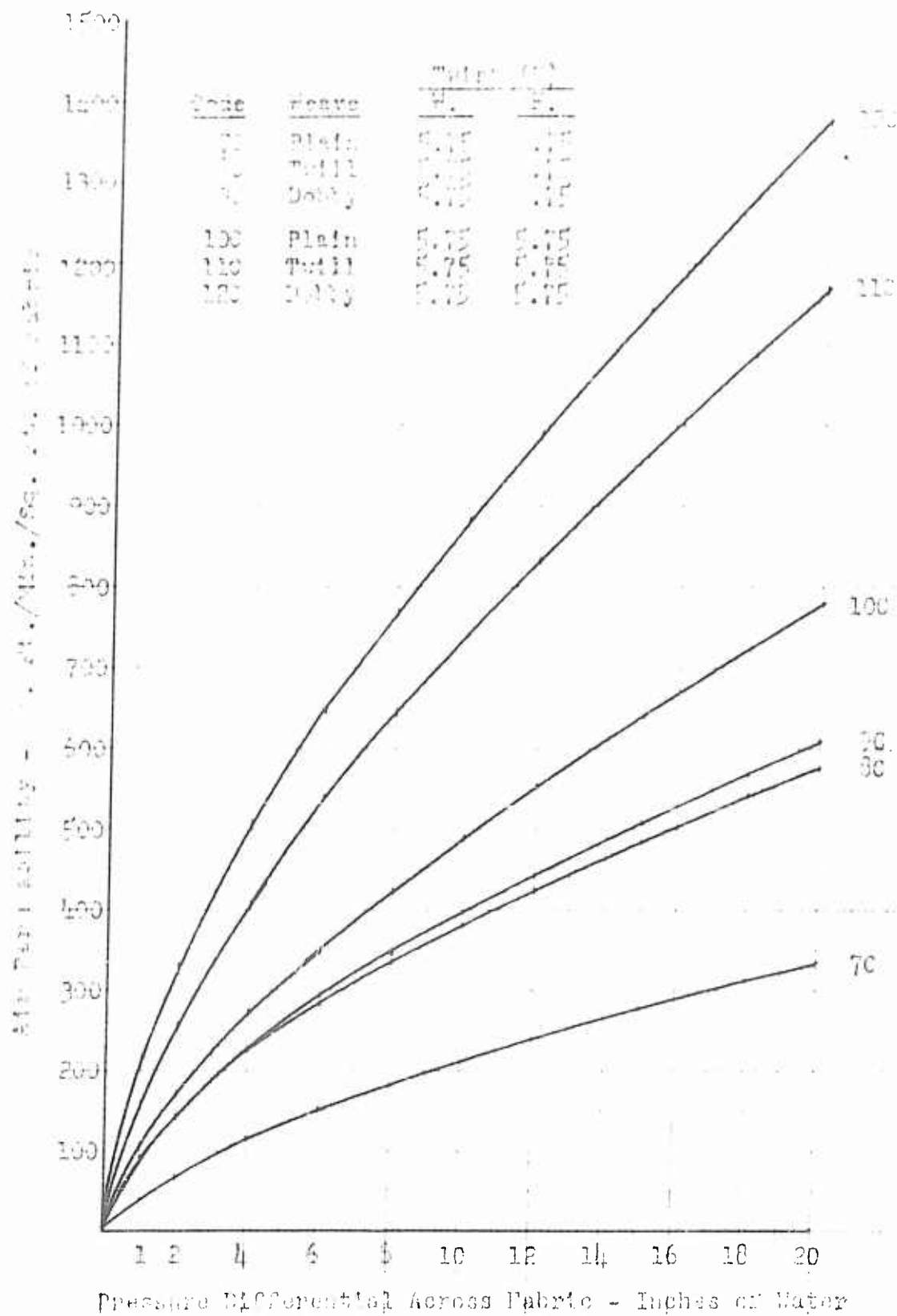


TABLE VII

AIR PERMEABILITY - $\text{FT.}^3/\text{MIN.}/\text{FT.}^2$ - FINISHED CLOTH

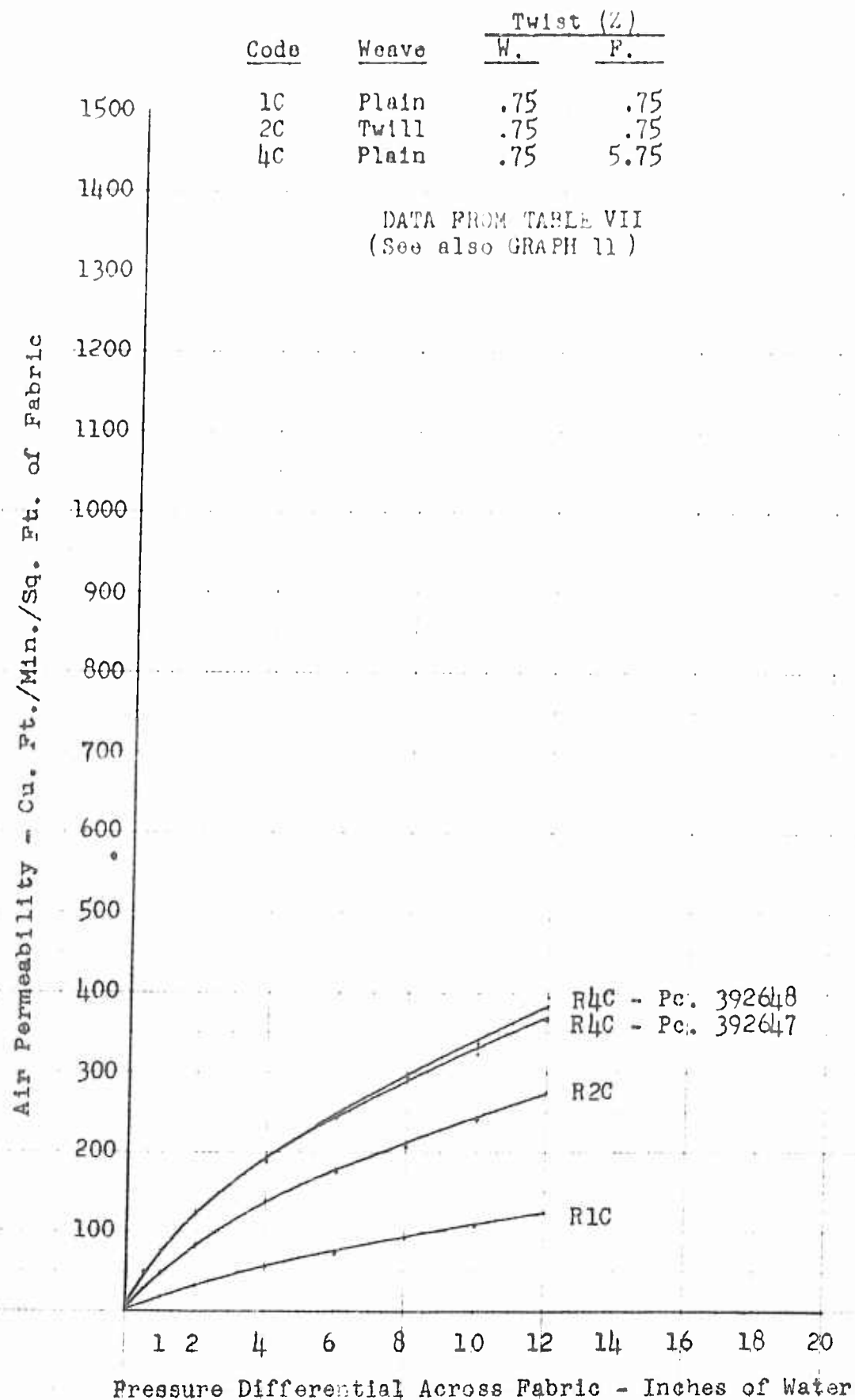
REPRODUCTION LOTS

Pressure Differential Across Fabric - Inches H_2O :	1/2"	1"	2"	4"	6"	8"	10"	12"
Code No.								
R1C	9.27	15.9	32.1	55.8	71.4	90.6	108.0	123.0
R2C	29.4	49.7	80.7	140.1	174.0	207.0	239.0	275.0
R4C - Pc.#392647	49.2	75.0	126.0	189.0	243.0	293.0	324.0	369.0
R4C - Pc.#392648	50.1	76.2	126.1	193.5	243.0	297.0	336.0	396.0

Cheney Brothers' Laboratory, U. S. Testing Co. permeability tester, 2 sq.in. sample area.

All Readings on Each Sample Made on One Marked Area Only, and
Without Disturbing Sample in Machine Until Series Completed.

GRAPH 6
AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL,
1/2" - 12", TESTS: REPRODUCTION LOTS R1C, R2C and R4C



SECTION II

DISCUSSION

A. MATHEMATICAL RELATIONSHIPS

1. A mathematical analysis of air permeability data from TABLE VI, tests made by the Wright Air Development Center Materials Laboratory on fabrics woven under this contract, discloses that the relationship, air permeability vs. pressure differential, is an exponential function that should result in a straight line when plotted on full logarithmic paper. (See also GRAPHS 7 through 11.) Additional data from tests made on over a hundred fabric samples and reported under other contracts (2, 3, 4, 5)* have been plotted and the results consistently bear out the above observation.

It also appears that the slope of the straight line plotted on logarithmic paper is an indication of the extent to which a fabric conforms to the concept of "Constant Effective Porosity" (1)*. (See APPENDIX I for mathematical development.)

It has been found empirically that the relationship between air permeability and pressure differential is adequately described by the following equation:

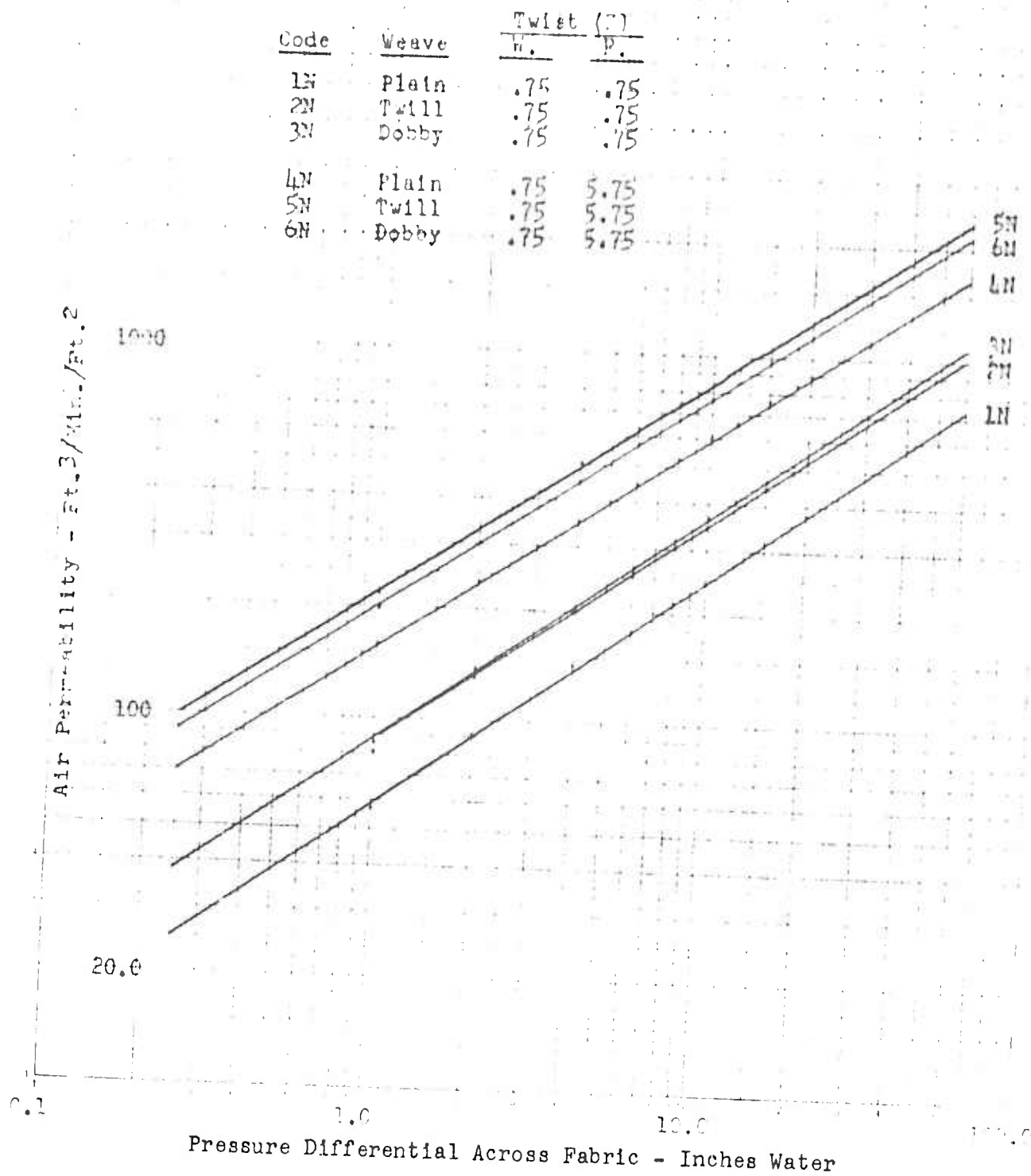
$$\log M_n/M_x = K \log h_n/h_x$$

where M_n and M_x are air permeabilities at pressure differentials of h_n and h_x , and K is a constant for any particular sample of fabric, but not the same value for all fabrics.

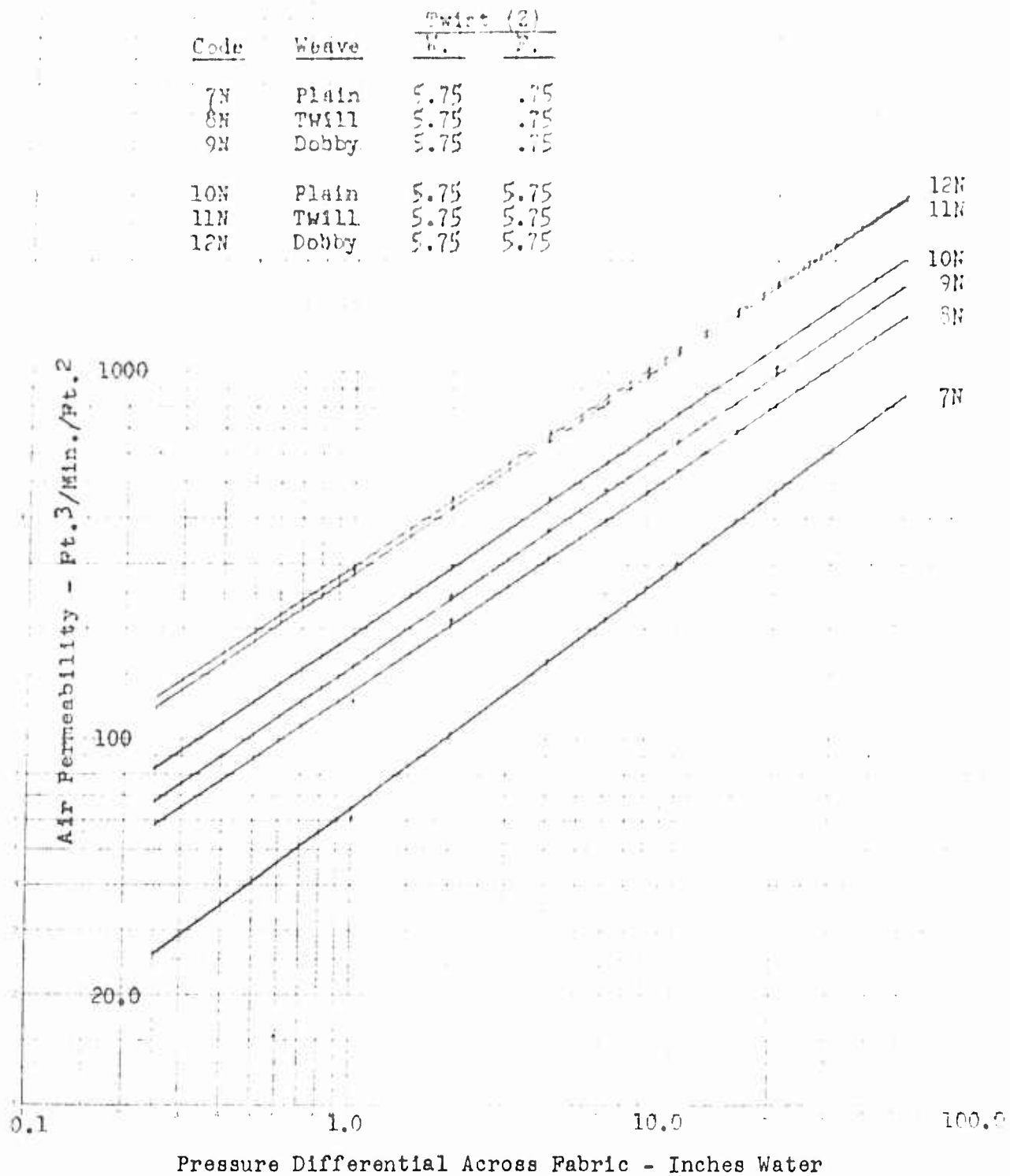
The test of the above relationship has been made in most cases by fitting a straight line to the data plotted on logarithmic paper and testing the fit by eye. For most of the data available, K has been determined by one or more of the methods described in APPENDIX II.

*APPENDIX III

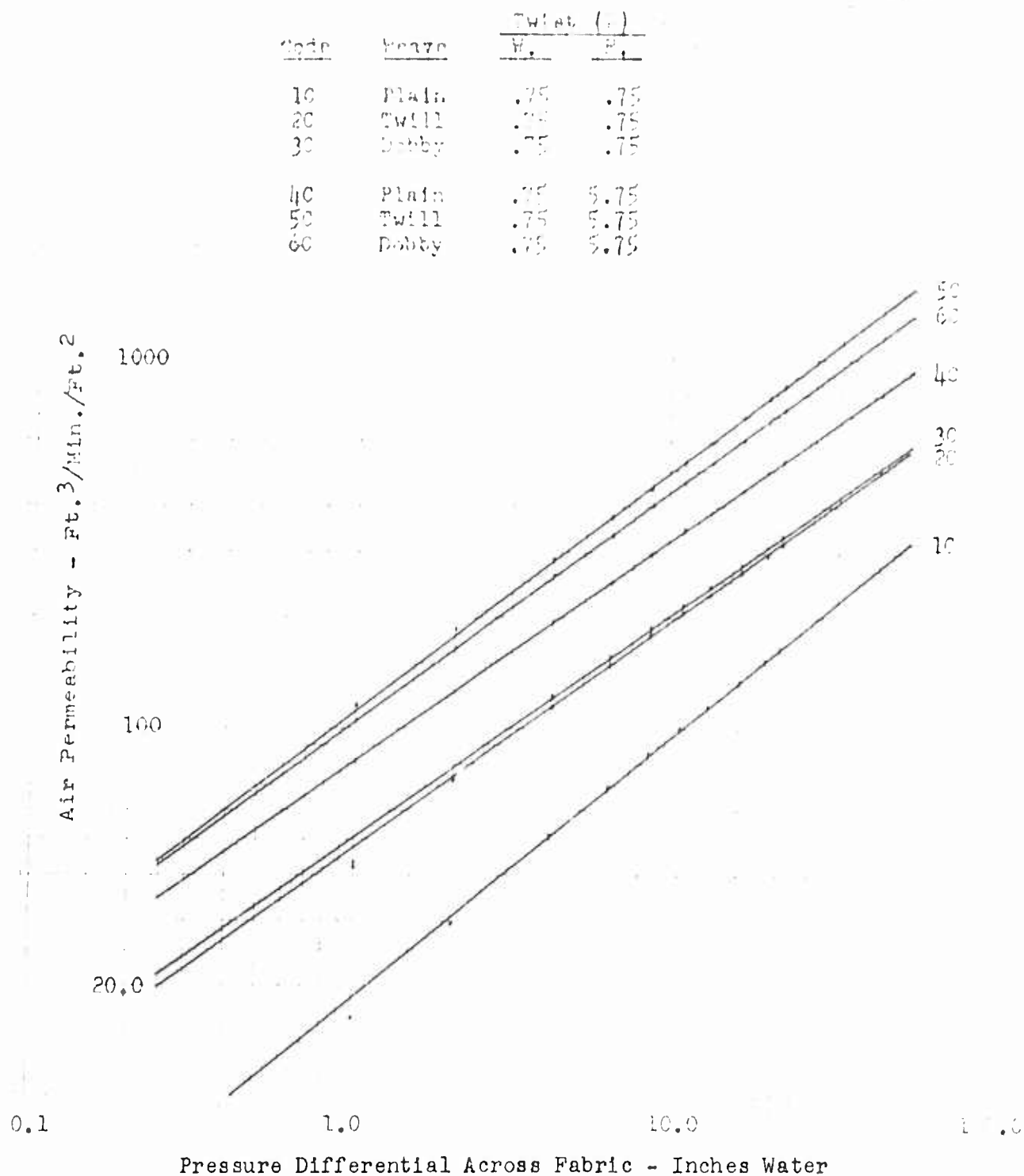
GRAPH 7
 (LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1N-6N
 DATA FROM TABLE VI
 (See also GRAPH 2)



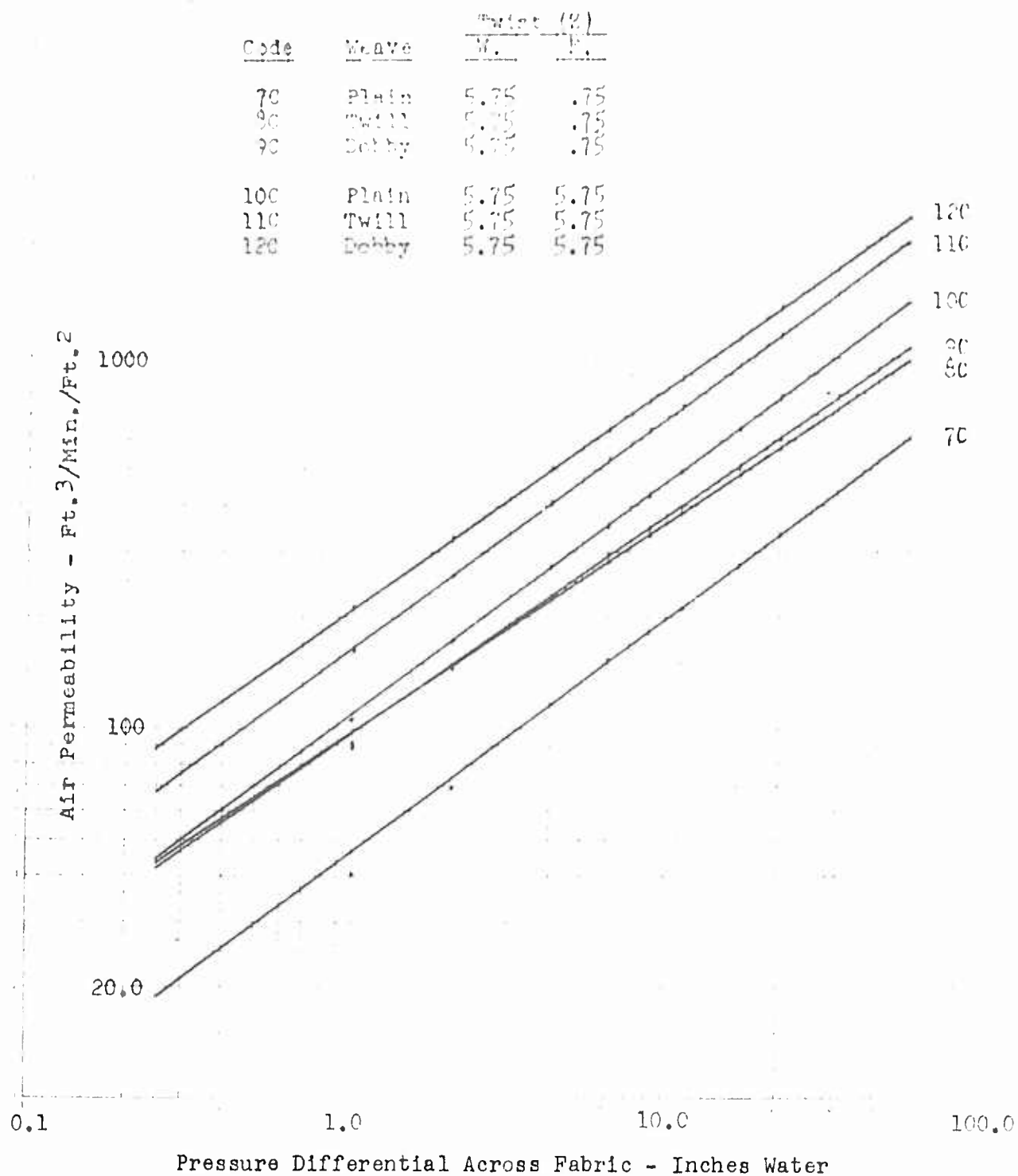
GRAPH 8
(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7N-12N
DATA FROM TABLE VI
(See also GRAPH 3)



GRAPH 9
(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 1C-6C
DATA FROM TABLE VI
(See also GRAPH 4.)



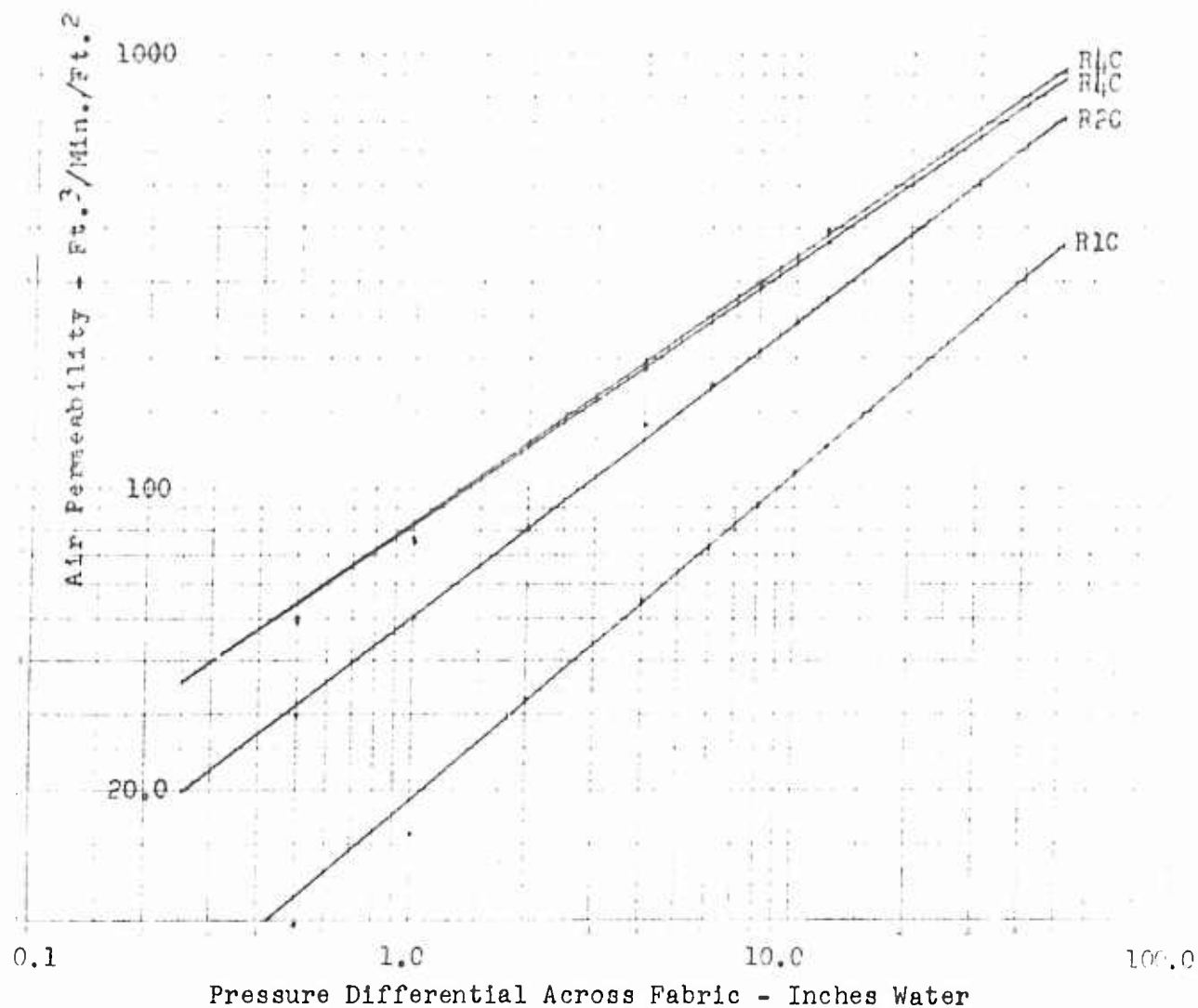
GRAPH 10
 (LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL, SAMPLES 7C-12C
 DATA FROM TABLE VI
 (See also GRAPH 5)



GRAPH 11
(LOG-LOG) AIR PERMEABILITY vs. PRESSURE DIFFERENTIAL,
1/2" - 12", TESTS - REPRODUCTION LOTS R1C, R2C and R4C

DATA FROM TABLE VII
(See also GRAPH 6)

Code	Weave	Twist (%)	
		W.	F.
R1C	Plain	.75	.75
R2C	Twill	.75	.75
R4C	Plain	.75	5.75



2. Significance of "K"

The value of "K" represents the slope of the straight line plotted on logarithmic graph paper and therefore defines the relationship between air permeability and pressure differential for the fabric represented. Fabrics having relatively higher permeability at higher pressures will show higher values of "K". The fabrics covered by our study have shown values of "K" ranging from 0.518 to 0.75. Published data for various tests on air flow through holes in metal plates and well-rounded metal orifices also show linear relationship with "K" values between 0.495 (5.0-inch diameter hole in metal plate .057 inch thick (6)*), and 0.539 for well-rounded 1 mm orifice. (Frazier's calibration for high pressure differential permeability tester.)

Some of the variables controlling "K" are indicated by this study, while others remain to be discovered.

One important variable controlling "K" appears to be the "distortability" of the fabric under increasing pressure differentials. Any variation in construction or finishing technique which makes it possible for a fabric to distort more readily tends to increase the value of "K". Some of these variations and the level of significance for the data obtained are shown in TABLE VIII. As can be seen in this table, data obtained under this contract and from study of the literature were sufficient to establish only filling twist and grey calendering as of definite significance. In all the other cases it was possible to study, the amount of data available was only great enough to establish trends.

TABLE VIII
FACTORS AFFECTING VALUE OF "K"

Source of Data	Fabric	Factors Affecting "K"	"K"	Level of Significance
Data from TABLE VI	2.25-oz. Nylon	Grey Calendered (1C-12C) Uncalendered (1N-12N)	.651) .604)	.001
		Weave of Calendered Goods		
		Plain	.675)	
		Twill	.644)	.10 - .50
		Dobby	.633)	
		Weave of Uncalendered Goods		
		Plain	.618)	
		Twill	.595)	.50
		Dobby	.600)	
		Filling Twist of Calendered Goods		
		3/4	.658)	.50
		5-3/4	.643)	
		Filling Twist of Uncalendered Goods		
		3/4	.622)	.005
		5-3/4	.587)	
		Warp Twist of Calendered Goods		
		3/4	.662)	.25
		5-3/4	.640)	
		Warp Twist of Uncalendered Goods		
		3/4	.597)	.25
		5-3/4	.612)	
(2)*	1.1 - 1.8-oz Nylon	Construction - Ends		
		70	.536	
		40	.535	
		50	.542	
		60	.577	
		70	.582	
		80	.580	
		90	.558	
		125	.569	
		125	.584	
		125	.601	
		125	.626	

*APPENDIX III

TABLE VIII continued
FACTORS AFFECTING VALUE OF "K"

Source of Data	Fabric	Factors Affecting "K"	"K"	Level of Significance
Cheney Brothers' Tests - for Georgia Tech. R & D. Contract dated 2/22/54	1.1-oz. Nylon Ripstop	Grey	.560	
		Finished - Uncalendered	.620	
		" - Grey Calendered 19 Tons	.680	
		" " 25 "	.690	
		" " 50 "	.680	
		" " 100 "	.660	
		" " 19 " , Heat Treated	.660	
		Calendered (Avg. 3)	.608	
		Uncalendered (Avg. 3)	.562	
		Filling Twist		
(4)*	1.1-oz. Nylon Ripstop (6 samples)	1/2 (Avg. 2)	.618	
		7 (Avg. 2)	.585	
		30 (Avg. 2)	.552	
		Calendered (Avg. 8)	.608	
		Uncalendered (Avg. 8)	.550	
		Filling Twist		
		1/2 (Avg. 4)	.654	
		5 (Avg. 4)	.590	
		15 (Avg. 4)	.538	
		35 (Avg. 4)	.536	
(4)*	1.6-oz. Nylon Twill (16 samples)	Warp Twist		
		7 (Avg. 8)	.581	
		10 (Avg. 8)	.578	

*APPENDIX III

3. Practical Use of "K" in Fabric Design

The controllable fabric construction factors which seem to affect "K" are:

Fabric Geometry

- Fiber
- Yarn size and filament count
- Weave
- Twist
- End and pick count

Processing Variables

- Grey calendering
- Various dyeing and finishing variables

Data obtained under this contract indicate three of these factors as of the greatest significance.

(1) When a grey fabric is calendered, the resultant permeabilities at both low and high pressure differentials are significantly reduced from those obtained on the same fabric finished without calendering. This is, of course, a well-known standard practice in the industry. However, the value of "K" is increased by this technique so that the permeability values for the higher pressures are not decreased in direct proportion to the decrease at 1/2-inch pressure.

(2) A second factor which shows considerable significance is a change of filling twist. As filling twist is increased, the "K" value decreases, probably because it makes a rounder, firmer yarn, less subject to distortion.

(3) A third factor which is important because it does not change the value of "K" significantly, but does change permeability, is a change in the amount of weight applied in calendering, once the fact of calendering is established. This is a valuable tool if the fabric is designed for a calendered finish, as it permits much closer control of permeability than would be practical if it were necessary to shift back and forth from a non-calendered to a calendered condition.

The other variables listed undoubtedly control "K" to some extent, but so far only enough data are available to indicate a trend; namely, that any factor that makes it easier for a yarn or fabric to distort under an applied pressure differential tends to increase the value of "K".

Example 1 - A fabric is desired which has a permeability at 1/2-inch pressure of 50 to 90 cu ft/min/sq ft and a permeability at 20 inches pressure of 500 to 700 cu ft/min/sq ft. Another fabric already in existence meets all the physical and chemical requirements, except that it has a 1/2-inch pressure permeability of 157 and a 20-inch pressure permeability of 1226. The "K" value is 0.557. The existing fabric has a filling twist of 5 turns "Z" and was not calendered in finishing.

By reference to TABLE IX or GRAPH 12, it will be seen that for a permeability range of 50 to 90 at 1/2-inch pressure differential, "K" values in the range 0.500 to 0.700 produce the required 20-inch value, although at the extremes of this range the low pressure tolerance would be too small to be practical. The best "K" value would be approximately 0.575, which would allow a 1/2-inch pressure permeability range of 60 to 85, or 72.5 plus or minus 17%. This tolerance, while narrow, could probably be met.

In order to produce the desired properties, the filling twist was decreased to 3.5 turns per inch and finishing planned to involve a calendering in the grey. Both of these changes increase "K", while decreasing the 1/2-inch permeability and the result is a fabric meeting the new specification.

Example 2 - Given the information included in TABLE V on the air permeabilities and values of "K" of the 24 samples woven under this contract, design one or more fabrics which will have an air permeability of 80 at 1/2-inch pressure differential and a 20-inch air permeability of 800.

The procedure followed here is to compare two samples which vary only in filling twist, and calculate the twist required to produce a 1/2-inch air permeability (M_1) of 80. For each such possible set, calculate the value of "K" for the resulting modification and the 20-inch differential permeability (M_{20}). Select the one or more results which are the closest solution to the problem.

Calculated Modification for $M_2 = 80$								
Weave	Code No.	Twist		M_1	"K"			
		Warp	Fill.			Fill. Twist	"K"	M_{20}
Plain	(1N	3/4	3/4	34	.645)	4.4	.595	719
	(4N	3/4	5-3/4	97	.576)			
Twill	(2N	3/4	3/4	52	.639)	2.37	.623	796
	(5N	3/4	5-3/4	138	.591)			
Dobby	(3N	3/4	3/4	57	.619)	2.63	.613	768
	(6N	3/4	5-3/4	118	.602)			
Plain	(7N	5-3/4	3/4	38	.675)	3.31	.642	855
	(10N	5-3/4	5-3/4	120	.610)			
Twill	(8N	5-3/4	3/4	77	.614)	.95	.614	771
	(11N	5-3/4	5-3/4	154	.625)			
Twill	(8C	5-3/4	3/4	62	.665)	3.48	.659	911
	(11C	5-3/4	5-3/4	95	.654)			
Dobby	(9C	5-3/4	3/4	60	.654)	2.79	.641	852
	(12C	5-3/4	5-3/4	109	.622)			

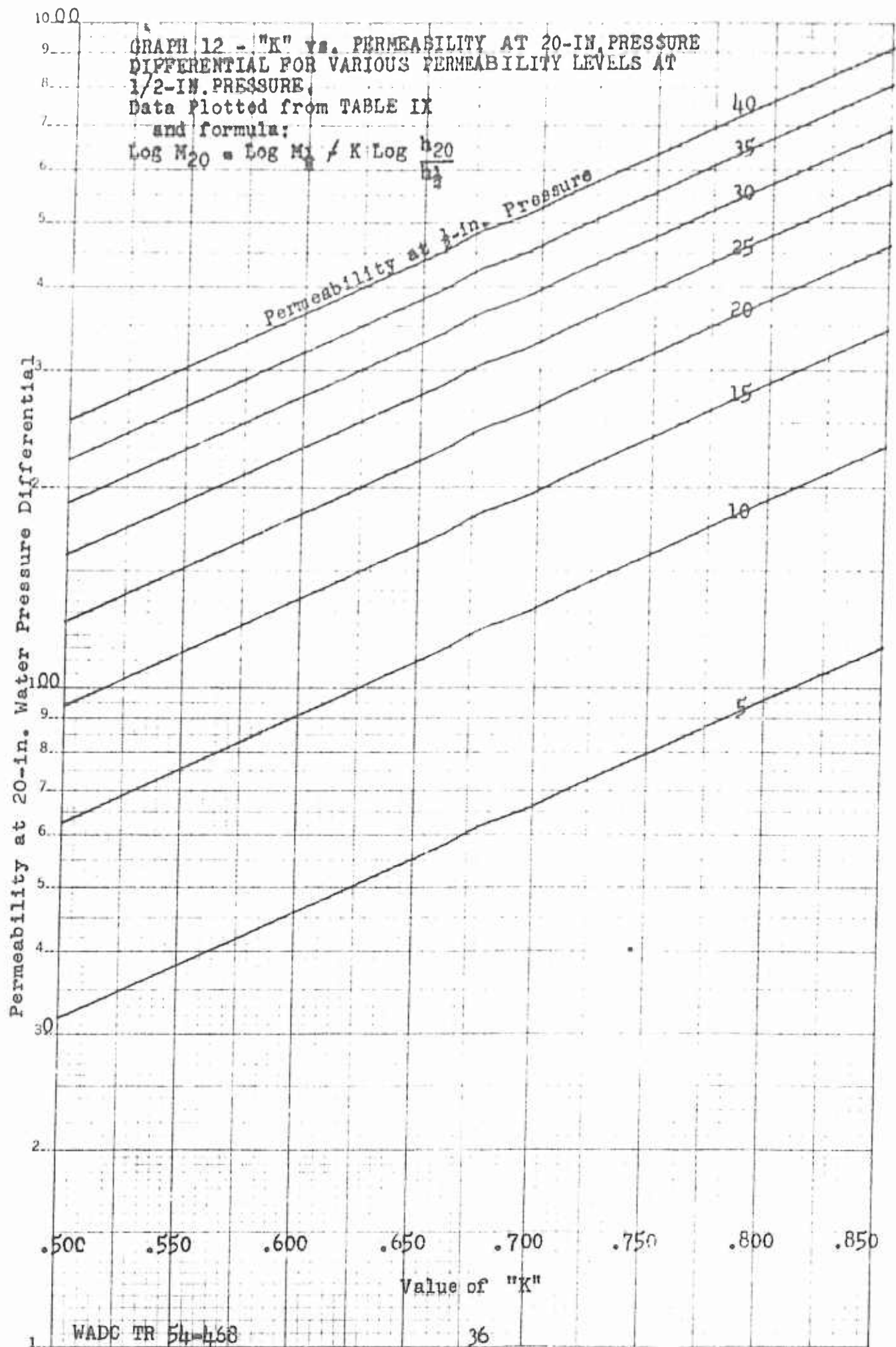
It can be seen that the modified fabric most closely fitting the specifications is the second one, Twill Weave, 3/4 twist in the warp, 2.37 twist in the filling, "K" = .623, 20-inch air permeability - 796. The other figures give an idea of the range of "K" and M_{20} which should be obtainable by modifying weave, warp twist, filling twist, and grey calendering. Another fact which can be seen here is the necessity of changing two variables simultaneously if "K" is to be changed while keeping M_1 constant.

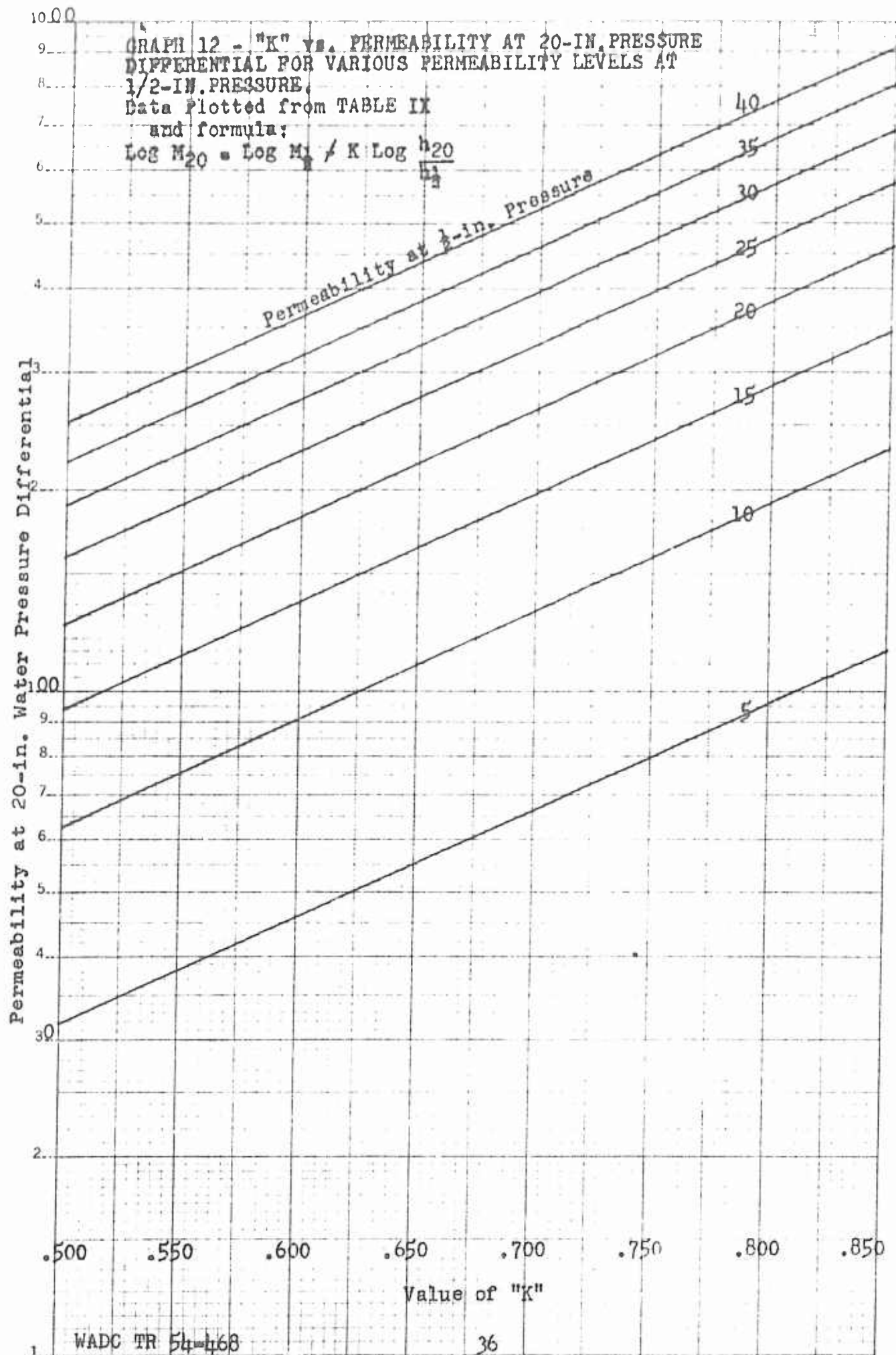
TABLE IX

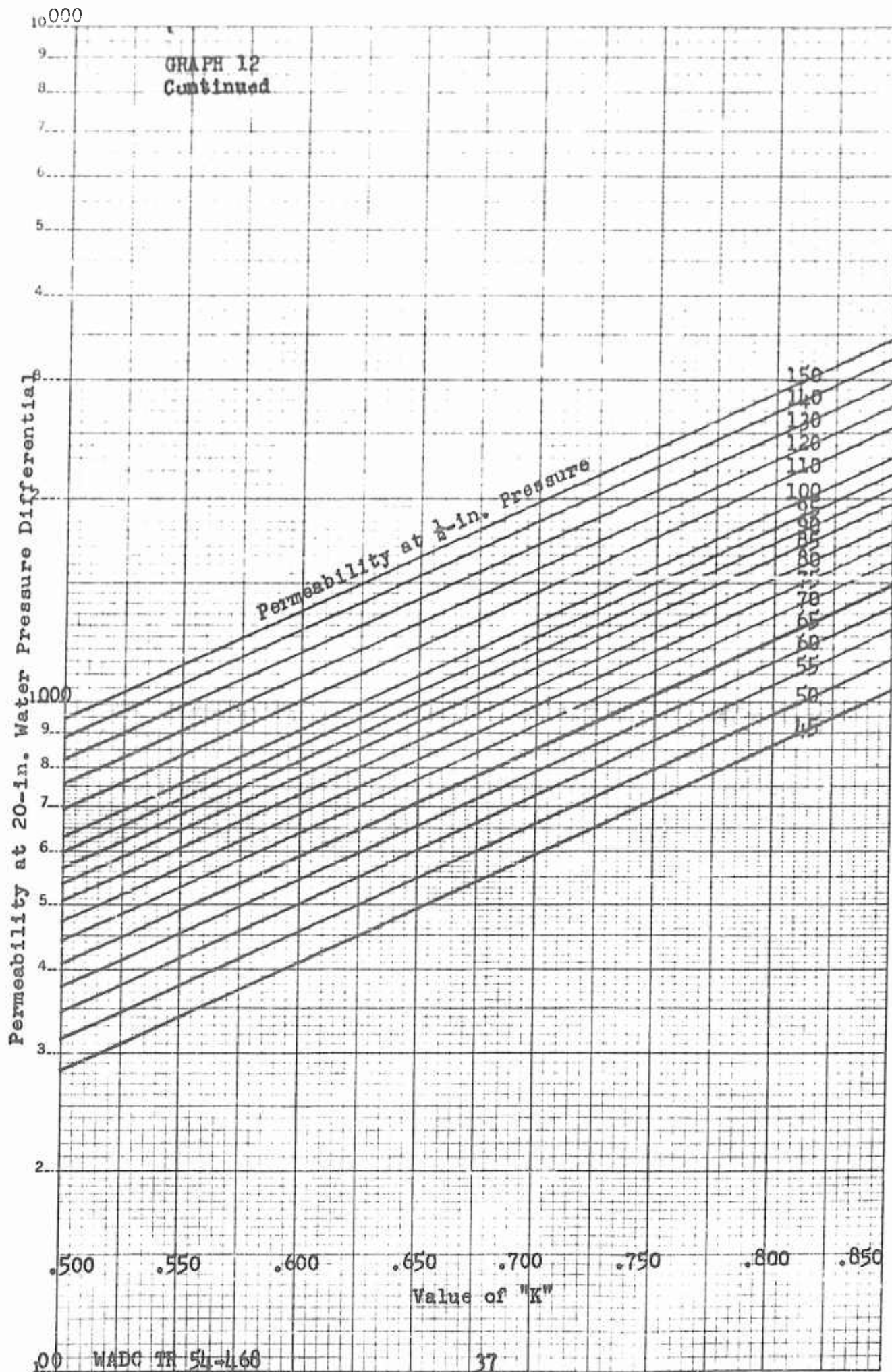
Calculated Values of Air Permeability (Cu Ft/Min/Sq Ft)
at 20-In. Water Pressure Differential for Different Values of "K"

Permeability at 1/2-in. Pressure	"K" .500	"K" .525	"K" .550	"K" .575	"K" .600	"K" .625	"K" .650	"K" .675	"K" .700	"K" .725	"K" .750	"K" .775	"K" .800	"K" .825	"K" .850
100	632	694	761	834	915	1003	1100	1206	1323	1450	1590	1744	1913	2097	2300
95	600	659	722	792	869	953	1045	1145	1256	1377	1510	1657	1817	1992	2185
90	569	624	684	751	823	903	990	1085	1190	1305	1431	1570	1724	1888	2070
85	538	590	646	709	777	853	935	1025	1124	1233	1352	1482	1625	1783	1955
80	506	555	608	667	732	802	880	965	1058	1160	1272	1395	1530	1678	1840
75	474	520	570	626	686	752	825	905	992	1088	1193	1308	1434	1573	1725
70	443	485	532	584	640	702	770	844	926	1015	1113	1221	1339	1468	1610
65	409	448	491	539	591	652	710	779	854	937	1027	1134	1243	1363	1495
60	379	416	456	500	549	602	660	724	794	870	954	1047	1148	1258	1380
55	348	381	418	459	503	552	605	663	727	798	875	959	1052	1153	1265
50	316	347	380	417	457	501	550	603	661	725	795	872	956	1049	1150
45	284	312	342	375	411	451	495	542	595	652	715	785	860	944	1035
40	253	277	304	334	366	401	440	482	529	580	636	698	765	839	920
35	221	242	266	292	320	351	389	422	463	507	556	610	669	734	805
30	190	208	228	250	274	301	330	362	397	435	477	523	574	629	690
25	158	173	190	208	228	251	275	301	331	362	397	436	478	524	575
20	126	139	152	167	183	201	220	241	265	290	318	349	383	419	460
15	94	104	114	125	137	151	165	181	198	217	238	261	287	314	345
10	63	69	76	83	92	100	110	121	132	145	159	174	191	210	230
5	32	35	38	42	46	50	55	60	66	72	80	87	96	105	115

Formula: $\log M_{20} = \log M_1 + K \log \frac{h}{h_1}$







4. "K" Value Correlation

TABLE X demonstrates the correlation between "K" values which can be obtained among different samples and between different laboratories. The data listed as taken from TABLE VI and TABLE V are derived from tests made by the Materials Laboratory, Wright Air Development Center, on two different sets of samples. The data under TABLE VI were from an average of five tests and the data under TABLE V were from one test taken in a single marked area on a different set of samples from those examined under TABLE VI. The rank order correlation in this instance is .883.

The data from TABLE IV were established by the Contractor testing a 2-sq in. area over pressure differentials of 1/2 inch to 12 inches. The comparable data from TABLE V give the same samples, testing within the same marked area, but over only a 1-sq in. area, by the Materials Laboratory at Wright Field. These two columns show a rank order correlation of .921.

It is probable that the correlation between TABLE V and TABLE IV would be better if the Contractor had had available an instrument that could test up to 20-inch pressure differentials, and if the areas tested had been exactly the same, rather than only within the same 2-sq in. area.

Assuming that the data under TABLE VI (Average of Five Readings) are the most nearly correct of the three sets, the rank order correlation between this information and that shown in TABLE IV (one set of readings taken over a pressure differential range of only 1/2 to 12 inches of water) is still .895.

TABLE X

"K" VALUE CORRELATION

Code No.	"K" Values Derived from Data in:				Deviation		
	TABLE VI "K"	TABLE V "K"	TABLE IV "K"	TABLE V-VI	TABLE IV-VI	TABLE IV-V	
1N	.624	.645	.630	.021	.006	-.015	
2N	.605	.619	.642	.014	.037	.023	
3N	.615	.619	.610	.004	-.005	-.009	
4N	.579	.576	.578	-.003	-.001	.002	
5N	.575	.582	.582	.007	.007	.000	
6N	.582	.602	.600	.020	.018	-.002	
7N	.665	.662	.692	-.003	.027	.030	
8N	.609	.614	.610	.005	.001	-.004	
9N	.613	.634	.630	.021	.017	-.004	
10N	.605	.610	.621	.005	.016	.011	
11N	.591	.625	.625	.034	.034	.000	
12N	.591	.611	.605	.020	.014	-.006	
1C	.740	.759	.793	.019	.053	.034	
2C	.663	.656	.720	-.007	.057	.064	
3C	.645	.647	.664	.002	.019	.017	
4C	.622	.621	.629	-.001	.007	.008	
5C	.658	.659	.730	.001	.072	.071	
6C	.643	.642	.645	-.001	.002	.003	
7C	.679	.710	.678	.031	-.001	-.032	
8C	.597	.648	.640	.051	.043	-.008	
9C	.626	.640	.635	.014	.009	-.005	
10C	.660	.661	.664	.001	.006	.005	
11C	.658	.654	.645	-.004	-.013	-.009	
12C	.618	.622	.641	.004	.023	.019	
Average Deviation				+.011	+.019	+.008	

Bank Order Correlation:

TABLE VI & V	-.883
TABLE VI & IV	-.895
TABLE IV & V	-.921

B. GENERAL COMMENTS

1. Weaving

No difficulty was experienced in connection with the producer's twist yarns in the warps of samples 1N through 6N and 1C through 6C. These trials seem to indicate that a fabric of this type made with 100 denier, 3/4 filament, Type 300 nylon warps could successfully be produced commercially with producer's twist in the warp yarns. This would not necessarily be equally true of lighter fabrics and other yarn sizes.

2. Finishing

Reproduction of identical permeability properties in reproduction lots was not accomplished merely by presumably making these lots in identically the same manner as the originals. Some reprocessing to readjust the permeability after initial finishing was resorted to, but did not fully accomplish the desired purpose. Exact control of permeability is not practical. A specification tolerance of not less than plus or minus 20% of the desired average is unavoidable.

3. Permeability Adjustments

(a) Calendering

The pressure used in calendering was the same for all of the calendered samples 1C through 12C and was relatively low pressure as compared to the capacity of the available machinery (7 tons used; 100 tons available). It is probable that all of the samples in this series could be made to yield the same permeability level merely by selecting the correct amount of pressure in the calendering of each. Furthermore, the permeability of the lowest of those shown can easily be reduced to much lower levels than those shown here (lowest, 1/2-in. water, 9 cu ft/sq ft/min; 20-in. water, 151 cu ft/sq ft/min).

(b) Twist

The amount of twist in yarns, and especially the filling twist, is again proven to be of major importance in establishing the permeability level. The addition of five turns per inch twist to the filling yarn alone results in doubling and tripling the permeability level. It is obvious therefore that variations in filling twist of as little as one turn per inch will result in significant variations in permeability. Twist variations of this magnitude are common and uncontrollable on even the most modern of commercial textile equipment. This again points up the fact that broad specification tolerances for permeability requirements are essential.

(c) Weave

These trials prove that weave does have a direct effect on permeability. The samples with plain (or taffeta) weave show the lowest permeability. The 2x1 twill and the dobby weave show a relatively slight difference. However, the number of binding points per square inch is approximately the same in both weaves and it seems evident that the permeability should not be too different.

C. CONCLUSIONS

No difficulty was experienced in producing fabrics which fell easily within the range of target properties. The data obtained seem to indicate clearly that it is possible to vary the air permeability characteristics at high and low differential pressures independently. In order to prove this finally and to establish limits, further experimental work is required, which was beyond the scope of this investigation.

The control of the value of the constant "K" is also a matter for further exploration, since the complete understanding of this control should greatly aid the designer of parachute fabrics in achieving his target properties.

APPENDIX I

MATHEMATICAL DEVELOPMENT

The following equations show the relationship of "K" to the concept "Effective Porosity" as described by Dr. Heinrich (1)*.

Symbols:

C	Effective porosity
ρ	Air density
V_1	Free stream velocity
V_2	Outflow velocity through fabric
M	Air permeability (cu ft/min/sq ft)
A	Air permeability at 1-inch pressure differential
K	Slope of line described above, a fabric constant
h	Pressure differential in inches of water
ΔP	Pressure differential in lbs/sq ft

$$(1) \text{ Empirical Formula - } \log M_n/M_x = K \log h_n/h_x$$

$$(2) C = V_2/V_1$$

$$(3) V_1 = \sqrt{2\Delta P/\rho}$$

$$(4) \Delta P = 5.2h$$

$$(5) V_2 = M/60$$

$$(6) V_1 = \sqrt{10.4h/\rho}$$

$$(7) C = V_2/V_1 = \frac{M}{60} \sqrt{\frac{\rho}{10.4h}}$$

$$(8) \log C = \log M / \log \frac{1}{60} \sqrt{\frac{\rho}{10.4h}}$$

$$(9) \log M/A = K \log h/1$$

$$(10) \log M = \log A / K \log h$$

$$(11) \log C = \log A / K \log h / \log \frac{1}{60} \sqrt{\frac{\rho}{10.4}} \sqrt{\frac{1}{h}}$$

*APPENDIX III

$$(12) \log C = \log \frac{A}{60} \sqrt{\frac{\rho}{10.4}} + (K - .5) \log h$$

$$(13) C = \frac{A}{60} \sqrt{\frac{\rho}{10.4}} \times h^{(K - .5)}$$

Accordingly C will be constant (at constant air density) only if "K" equals 0.5. For values of "K" greater than 0.5, which is the general case, C will not be constant, but will follow the equation:

$$(14) \log C_n/C_x = (K-.5) \log h_n/h_x$$

which is very similar to the original equation:

$$(1) \log M_n/M_x = K \log h_n/h_x$$

differing only by the slope of the line representing this relationship. Obviously a change in the value of "K" will result in a greater proportional change in (K-.5). For example, a 20% increase in "K", from 0.600 to 0.720, would result in a change in (K-.5) from 0.100 to 0.220, an increase of 120%.

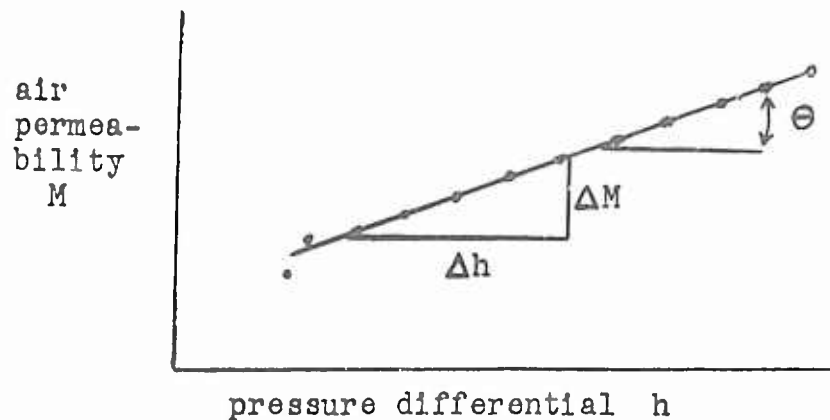
APPENDIX II

METHODS OF DETERMINING "K"

In the following methods for determining "K" it is assumed that readings of air permeability have been taken at several pressure differentials. It has been found as a general observation that the values of air permeability at pressure differentials above 2 inches of water more consistently lie on a straight line. At the lower pressure differentials of 1/2 inch and 1 inch, the points are apt to lie either above or below the best straight line for the rest of the points. For this reason, in calculating or otherwise measuring "K", it is best to disregard the lowest value obtained if it lies more than 10% away from the theoretical value given by the extrapolated straight line from the rest of the points. This results in the most accurate value of "K" for use in extending the line to pressure differentials higher than those measured. The following methods are suitable for determining "K":

A. Graphical Method

Plot values of air permeability vs. pressure differential on logarithmic graph paper. Draw the best representative straight line through the points plotted. The lowest points may not lie on this line (see above). Experience has shown that for other points which do not lie on the line, there is usually some explanation, as a typographical error or error in calculating air permeability.



(1) Measure ΔM and Δh . K equals $\Delta M / \Delta h$

or

(2) Measure the angle Θ with a protractor. $K = \tan \Theta$.

It is usually advisable to plot the points before going to either of the following mathematical methods of determining "K", since obvious errors which can easily be seen on a graph may not be picked up when only the figures are used.

B. Simplified or Short Form Method

Use values of air permeability obtained at any two pressure differentials such that the higher pressure is ten times the lower pressure. Subtract the logarithm of the lower air permeability from the logarithm of the higher air permeability. The answer is "K" directly. Best results are obtained if it is known from plotting that both points lie on the best straight line. Of the combinations $\frac{1}{2}$ -5 inches, 1-10 inches, 2-20 inches, the latter is more likely to give accurate results for the reasons given above.

C. Method of Least Squares

"K" can be calculated very exactly, providing that the precautions outlined above are taken; that the points be plotted first, errors due to typography or prior calculations corrected, and the accuracy of the lower points be evaluated. Using the following symbolism:

h = pressure differential (any units)
M = air permeability (any units)
N = number of different readings used

$$K = \frac{\sum (\log h)(\log M)}{\sum (\log h)^2} = \frac{(\sum \log h)(\sum \log M)}{N}$$

APPENDIX III

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