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INVESTIGATION OF METHODS FOR DETERMINING THE FILLING POWER OF FEATHERS

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FOREWORD

The laboratories at the Philadelphia Quartermaster Depot have been faced on more than one occasion with a multiplicity of tests designed to measure a single property of textile fibers. Before standardization of any given test method it has been the practice to investigate thoroughly the characteristics of each technique to establish its sensitivity, variability and ease of operation and the general availability of the apparatus in the industry concerned with production of the material to be evaluated.

The study reported here is concerned with establishing the optimum method for determining the filling power of feather and down mixtures both as a research tool and as an acceptance quality control measurement. Similar studies have been carried out during the war on water repellency, air permeability, breaking strength, stiffness, and thermal conductivity tests. Results of such investigations will be discussed in future reports in this series.

STANLEY BACKER
Technologist

December 1946

EVALUATION OF FILLING POWER OF FEATHER AND DOWN MIXTURES

INTRODUCTION

The need for a reliable method to measure the space-filling ability of feathers was recognized as a result of the experience gained during World War II by the Army Quartermaster Corps in its procurement of the millions of pounds of feathers required for such items as sleeping bags and pillows. Inadequate devices for evaluating feathers were hampering not only the procurement program by seriously limiting the quality control that could be exercised, but the research program as well, by rendering it most difficult to recognize the relative efficiency of various other types of filling materials which were studied as possible substitutes for the standard 40% down--60% waterfowl feather mixture because of the critical supply situation.

This standard combination (hereafter referred to simply as 40/60) was found to be superior to almost all other substances considered with respect to filling power. While some few materials were found to possess greater filling ability* than 40/60, their use was not deemed advisable because of their inability to meet military requirements of laundering and matting resistance, and fluffability.

Of the various qualities possessed by feathers, the first most prominent characteristic was considered to be the space-filling ability of the feather mass, for experience with waterfowl feathers had indicated that compressibility, resilience, and warmth were related to filling power. Hence, work was undertaken at the Philadelphia Quartermaster Depot to provide a method which would measure the filling power of feathers and thus provide an objective means of rating feather quality.

Prior to the time the tests described below were undertaken, many tests of feathers on the compressometer modification of a standard inclined plane machine had indicated that resilience was associated with filling power. However, it is believed that the use of too large a quantity of feathers for the feather-holding cylinder and use of too great a compressive load on the feathers, seriously limited the sensitivity of this compressometer method. The method had another disadvantage in that it required the use of an expensive apparatus found only in a textile laboratory and normally not considered standard equipment in a feather processing plant.

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* The terms filling ability and filling power are used interchangeably and refer to the space-filling characteristics of fibers or feather-like materials.

It was suggested that a hydrostatic method be used in which the specific volume of the feathers would be obtained by measuring the volume of water displaced by a unit weight of feathers contained in vented waterproof bag submerged to a prescribed depth to attain a given hydrostatic pressure.

On another occasion it was suggested that the weight of a known volume of feathers be obtained by filling a large box and determining its weight but so far as is known this method was not used for filling-ability measurements of feathers. Preliminary investigations of testing methods indicated the desirability of using low pressures for detecting small differences in filling power of feathers and led to modifications of the above technic wherein the volume of a given weight of feathers was determined when fluffed into a large box ("box" and "zero load" methods). The use of the term "bulking value" as a measure of the volume in cubic inches occupied by one ounce of material when under a pressure of 0.005 lbs. per square inch (psi) was suggested and used by the National Bureau of Standards and the Department of Agriculture. The bulking-value method consisted of filling a large glass graduate of 11-3/4" diameter with feathers and adding weights to a loose-fitting piston to give the required pressure. Analysis of mixtures, each component of which had a known bulking value, in many cases failed to satisfy the expectation that the bulking value of a mixture should equal the weighted average of that of the components. Further, the variability of this method, as far as is known, has never been determined.

In summary it may be stated that a number of methods were conceived(1,2,3,4), all based fundamentally on a means of measuring the space occupied by a known weight of fill under a known pressure. The pressures to be used in testing were not generally agreed upon, nor had the method of filling the test container with feathers been given much consideration. The rate of applying pressure and its duration had been considered, to a slight degree. Ambient atmospheric conditions were usually controlled at 70°F and 65% relative humidity.

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(1) U.S.D.A. Yearbook p 782-4 (1926) - J. I. Hardy describes devise for measuring density of wool fleece.

(2) N.B.S. Jour. of Research 10,6, 705-13 (1933) - H. F. Schiefer describes a compressometer capable of applying loads from 0.1 to over 2 psi and gives results of thickness resilience and compressional resilience of fabrics and other materials.

(3) A.S.T.M. Preprint Report of Committee B-1, p 23-7 (1931) W. E. Emely discusses thickness of compressible materials.

(4) U. Sci. Instr. Vol 6 p 382-85 (1929) M. C. Marsh describes an instrument for measuring thickness of textiles using pressures which can be varied from 1 mgm to 100 Gm/cm^2.

PURPOSE

For the program described herein several tests were designed to answer the following pertinent questions:

1. What is the best method available for distinguishing between the filling ability of different grades of feathers?

2. Does pounding (as an accelerated serviceability test) affect good grades less than poor grades of feathers? That is, can resistance to pounding be used to distinguish the quality of the feathers?

3. To what pressures are the feathers lining the bottom of the sleeping bag subjected by the sleeper?

As regards Question 1, from previous observation it seemed reasonable to assume that pressures as near zero as possible would indicate maximum differences in filling power. A second important consideration was that a technic be used by which random distribution of the material in the test chamber could be effected. The implication of Question 2 was that poorer qualities would show the largest decrease in percent of original filling power after pounding on the assumption that older or poorer grades would be more brittle, hence subject to faster disintegration. Question 3 arose from the fact that search of the literature failed to reveal in detail the information sought on pressure distribution in bedding items.

EXPERIMENTAL PROCEDURE

Preparation of Feathers. Five different grades of feathers (identified in Table 1) were treated as nearly alike as possible in washing, mixing, pounding, sampling, and testing. Washing was accomplished in a standard rotating washing machine into which the feathers were placed enclosed in loosely woven bags. The feathers were spun in a centrifugal extractor to remove excessive moisture, and completely dried in a heated tumbler. They were then placed on a table and layered by hand fluffing into a large bin, removed in sections, and relayered until thorough mixing (3 separate relayerings) had occurred. During the operation of fluffing foreign matter and chaff were excluded from the feathers.

Pounding of Feathers. A portion of the processed feathers were set aside for immediate evaluation of filling power while the rest were subjected to a preliminary test of durability prior to measurement

TABLE 1

Analysis of Five Different Grades of Feathers by Percentage Composition and Corresponding Subjective Rating

Lot	A	B	C	D	E
Physical Composition					
% Down	16.6	9.7	29.69	1.5	25.5
% Fiber	3.6	10.1	8.41	22.5	0.8
% Whole Feathers	36.8	15.4	59.50	3.3	42.2
% Broken Feathers	39.1	56.7	0	59.9	29.7
% Chicken Feathers	2.6	6.2	0	2.7	0.8
% Residue	1.3	1.9	2.40	10.1	1.0
Total %	100.0	100.0	100.0	100.0	100.0
Feather Expert's Rating					
Used or New	Slightly Used	Used	New	Used	Slightly Used
Condition of Lot	Good	Fair	Excellent	Disintegrated Almost to a Powder	Very Good
Quality	Good	Fair	Excellent	Very Poor	Very Good

Source: Results of tests performed at the Philadelphia Quartermaster Depot

of filling power. Several two-ounce samples encased in tightly woven bags were placed in the chamber of a specially constructed pounding machine (Figure 1), and pounded, for the times given in Table 2, with a hammer weighing 30 pounds dropping a distance of 6 inches, 50 times a minute. Pounding was seen to twist and rotate the bags so that all bags were in direct contact with the hammer at some time.

Conditioning of Feathers. The feathers were conditioned to approximate moisture-content equilibrium at 65% R.H. and 70°F, sampled at random and tested for filling power by the methods described below. Feathers tested by the box method were not conditioned, the atmosphere during testing varying from 75° to 90°F, and from 40% to 85% R.H.

Inclined Plane Compressometer. The inclined plane machine (Scott IP2 Model Serigraph) manufactured for the testing of textile yarns is shown in Figure 2 converted for use as a relatively* constant-rate-of-load compressometer. Attached to the trolley portion is a rigid rod at the end of which is a piston free to drive into a removable brass cylinder (dia. 3.85", length 5.30", inside dimensions) at the extreme right of the inclined plane. Also attached to the trolley is an autographic pen which records on a chart the vertical displacement of the plane (load) and the parallel displacement of the piston into the cylinder (compression).

In use, the cylinder is removed, filled with 20 grams (0.04 pound) of prefluffed feathers, weighed accurately to within 0.1 gram, and replaced in the machine. As the machine is started the plane descends and a constantly increasing pressure is placed on the feathers until a maximum of 100 grams per square inch (.22 psi) is reached. At this point the plane has reached its maximum descent, that is, 25° of revolution from the horizontal. The plane is then automatically raised, thereby releasing the load at a constant rate. The time for completion of the descent-ascent cycle of the plane is 110 seconds. Figure 2 shows the plane at maximum descent and Figure 3 represents an autographic chart, showing a test on one sample of feathers consisting of three typical compression-relaxation curves together with inserted notations for measuring at pressures of 0.22 and 0.02 psi** respectively the "X" and "Y" filling-power values of the feathers (to the nearest hundredth inch).

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* Because of higher friction at the "Y" pressure (approximately .02 psi) when the carriage is in an almost horizontal position there is a slight deviation from constancy of load application. Another loading variable is introduced by carriage inertia. Likewise a small error is inherent in the construction of, hence registration of the load-compression recording mechanism of the machine.

** These figures represent approximations from 0.221 and 0.0185 psi for the X and Y pressures respectively.

TABLE 2

Filling Power* Values of Various Grades of Feathers Before and After Dry Pounding Measured by Three Methods

Method	Test Pressure (PSI)	Hours Pounded	Filling Power Lot A	Filling Power Lot B	Filling Power Lot C	Filling Power Lot D	Filling Power Lot E	Standard Deviation Lot A	Standard Deviation Lot B	Standard Deviation Lot C	Standard Deviation Lot D	Standard Deviation Lot E
Box	.0006	0	16.3	13.4	21.2	7.2	19.2		None calculated for Box Method because of insufficient data			
		1½	13.9	10.3	17.8	6.1	15.1					
		6	13.7	9.8	16.8	5.8	14.9					
		10	11.0	9.1	16.6	5.2	13.7					
Inclined Plane "Y" Values	.018	0	2.44	2.14	2.81	1.60	2.49	0.093	0.065	0.060	0.054	0.064
		1½	2.33	1.99	2.78	1.52	2.40	.024	.035	.046	.028	.073
		6	2.25	1.85	2.78	1.46	2.35	.049	.017	.043	.036	.030
		10	2.24	1.84	2.74	1.40	2.24	.057	.045	.054	.020	.061
Inclined Plane "X" Values	.22	0	1.70	1.46	2.08	1.26	1.96	0.046	0.052	0.059	0.050	0.062
		1½	1.76	1.53	2.01	1.21	1.82	.010	.048	.052	.014	.037
		6	1.73	1.45	2.02	1.15	1.77	.000	.030	.040	.040	.022
		10	1.69	1.42	1.97	1.10	1.68	.006	.028	.042	.031	.041
Hydrostatic	.14	0	14.8	13.1	17.6	10.4	15.5	0.28	0.22	0.35	0.24	0.51
		1½	14.3	12.6	17.2	9.9	15.1	.23	.28	.46	.36	.54
		6	14.0	12.0	16.8	9.4	14.8	.46	.32	.34	.41	.47
		10	13.4	11.5	16.4	9.0	14.5	.23	.42	.26	.45	.53

*Filling Power is expressed as follows for each method:

Box Method. Height (inches) of 2 lbs. of feathers when fluffed into a box 2 feet square when under a load of 0.0006 psi.

Inclined Plane Method. Depth (inches) of 20 grams (.04 lb.) of feathers contained in a rigid cylinder 3.85 inches in diameter when compressed to approximately .02 and 0.22 psi respectively for the "Y" and "X" values.

Hydrostatic Method. Cubic centimeters per gram when one pound of feathers contained in an 18 inch square pillow and a vented waterproof bag is submerged in water to an average depth of 4 inches.

Source: Results of tests performed at the Philadelphia Quartermaster Depot

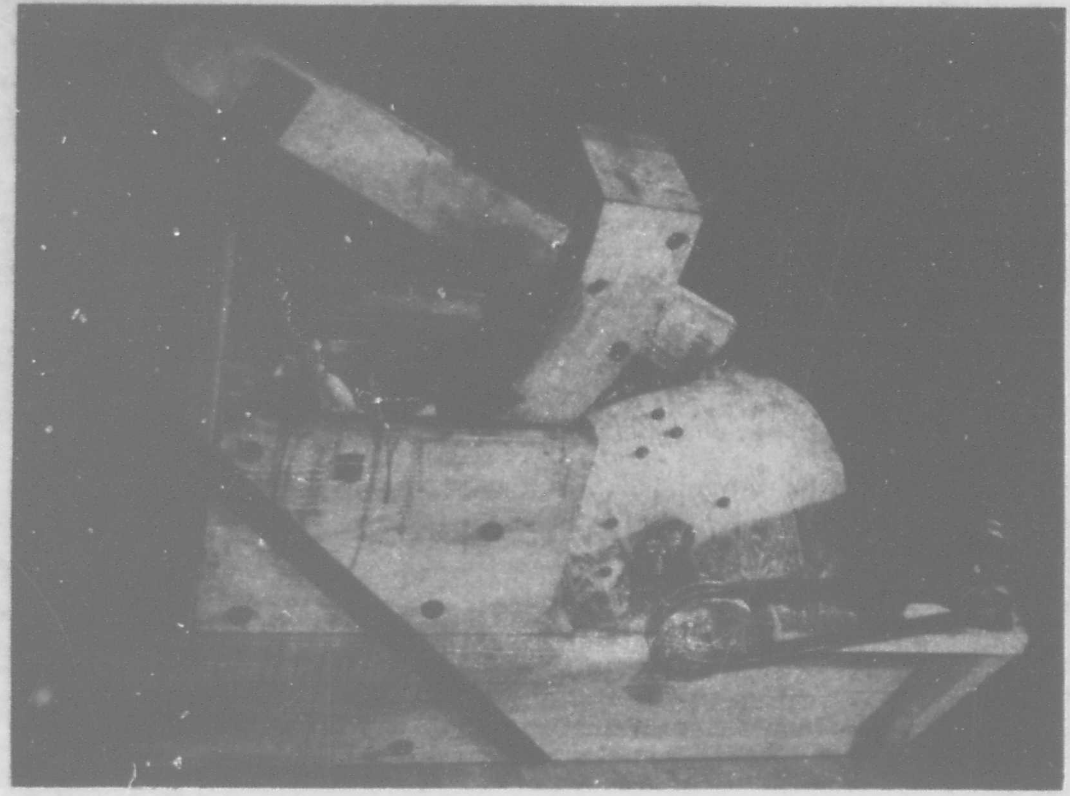


FIGURE I

POUNDING MACHINE

Used to pound feathers to test their durability (described in Journal Society Dyers and Col., Dec. 1942)

Weight of Hammer - 30 lbs.

Strokes per minute - 50 (approx.)

Height of stroke - 6 inches (approx.)

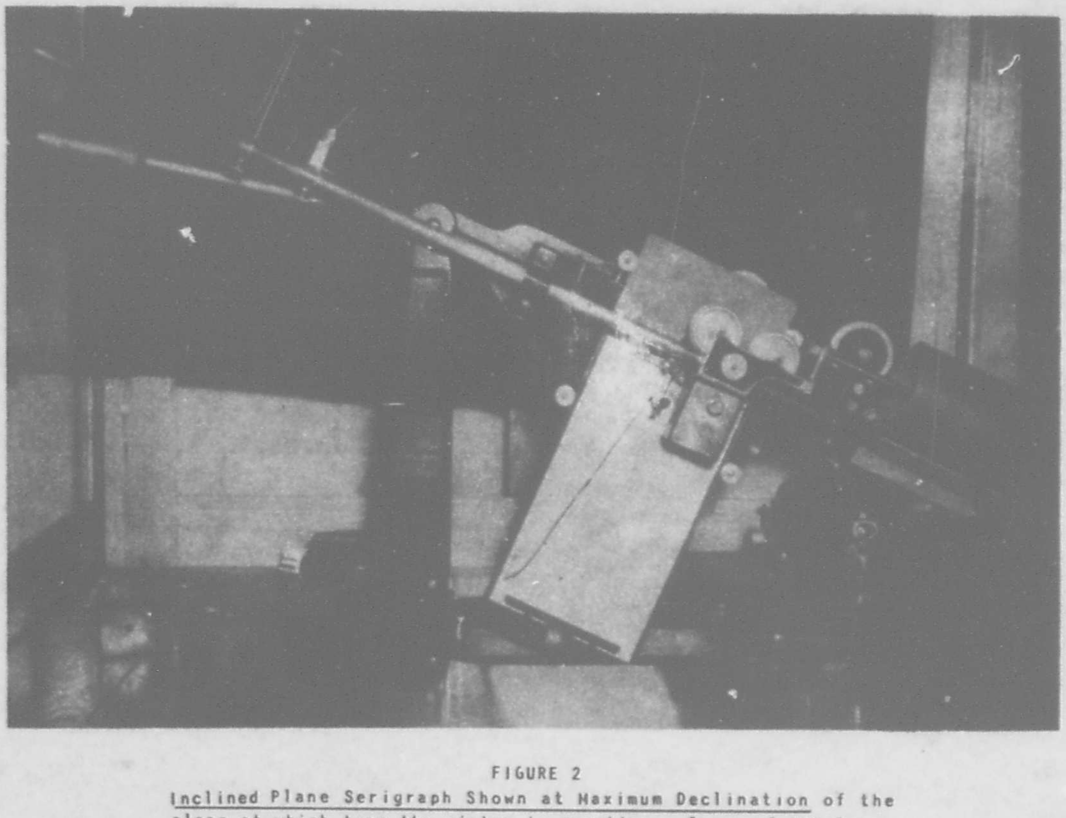
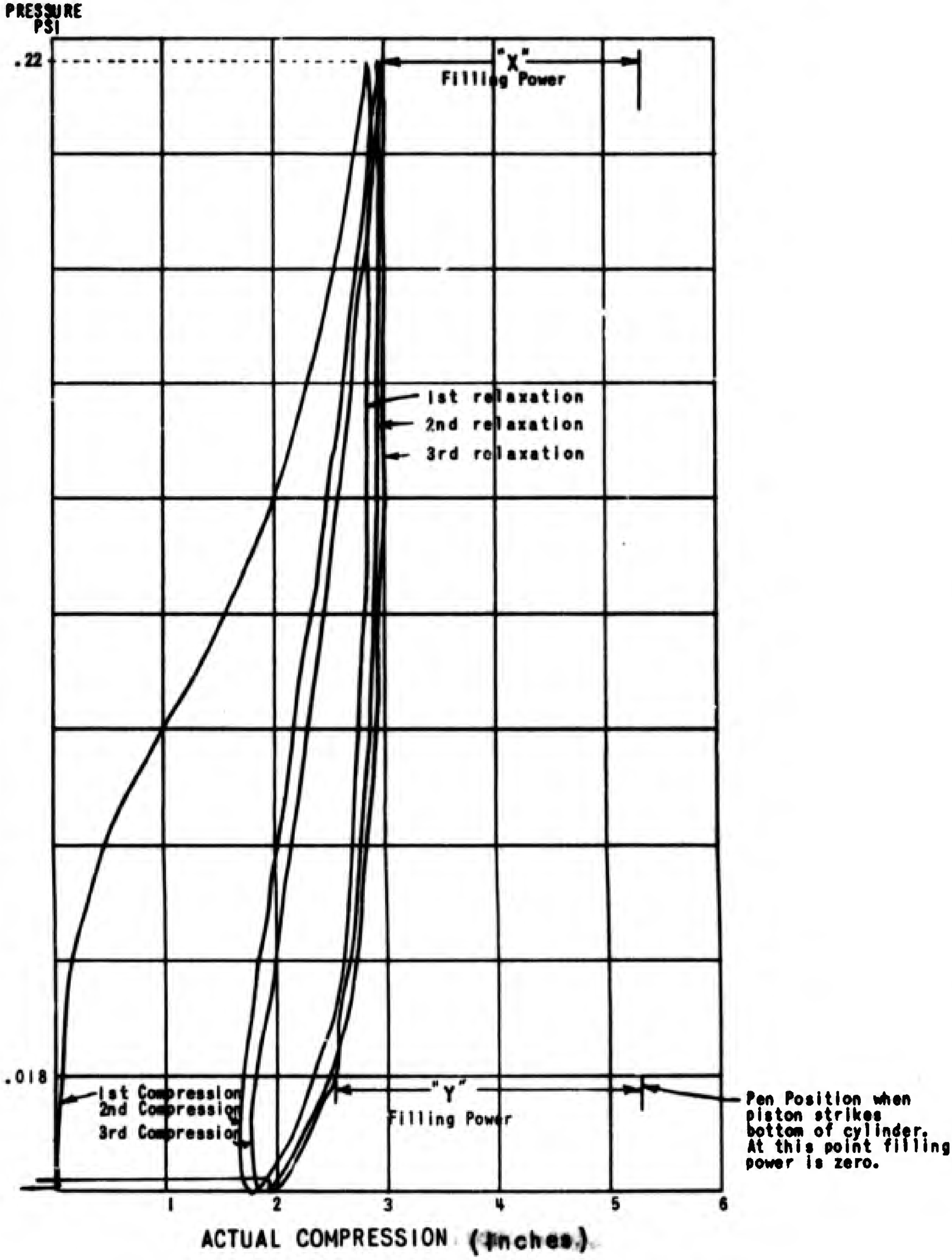


FIGURE 2

Inclined Plane Serigraph Shown at Maximum Declination of the plane at which time the piston is exerting a force of 100 Grams per square inch on the feathers in the Cylinder at the extreme right.



TYPICAL LOAD COMPRESSION CURVES DRAWN BY THE INCLINED PLANE APPARATUS WHEN TESTING FEATHERS USING THREE CYCLES OF OPERATION

Source: Results of tests performed at the Philadelphia Quartermaster Depot

FIGURE 3

Hydrostatic Method. Initial measurements made volumetrically of the volume of water displaced by a one-pound sample of feathers when submerged indicated the desirability of a gravimetric method to increase the sensitivity. Figure 4 shows the gravimetric method apparatus used; this consists of a two-foot square tank over which is mounted a platform scale accurate to ± 0.03 pound with a submersion assembly consisting of a thirty-pound perforated steel frame slightly smaller than the inside of the tank, held by a rope attached to a windlass.

In use, an 18" square pillow is filled with one pound of feathers and placed in a vented waterproof vinyl bag. This is floated in the tank beneath the submersion frame with the mouth of the bag extending out of the water. As the windlass is released, the submersion frame pushes the pillow beneath the surface of the water to a mean depth of four inches* as determined by the length of the rope attached to the scale platform. After two minutes** the weight of the submerged pillow and frame is noted on the scale. From this weight is subtracted the weight of the submersion assembly when sunk to the same depth without feathers. This difference indicates the net upward push exerted by the water on the feathers. To this must be added the weight of the feathers used to obtain the total buoyant force which can readily be converted to denote the volume of water displaced and thus the volume occupied by one pound of the material under test. The buoyancy value is thus identical to the specific volume*** of the feathers.

Box Method. The apparatus (Figure 5) for the box method consists of a reinforced cardboard carton measuring 24 x 24 x 27 inches. A piston is made by cutting out the center of one of the box liners to leave a two-inch frame over which is tacked mosquito netting. Pieces of twine are attached to the frame for suspension purposes. The inside of the carton is marked off in inches on each wall starting at the bottom of the box. In use, two pounds of feathers accurately weighed to ± .01 pound are fluffed by hand into the box, allowing the feathers to fall freely. After two minutes the piston is gently laid on the feathers and two minutes later the height of the frame is noted on each of the four walls to the nearest one-quarter inch. The four "height" readings thus obtained are averaged thereby indicating the filling power of the material. The feathers are then relaxed by spreading on a table for two minutes before retesting.

Zero Load Method. Attempts were made to measure the height of two pounds of feathers fluffed into the box without the use of the piston. Results by this "zero-load" method, however, were so indefinite that it was deleted from further consideration.

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* A four inch submersion depth corresponds to a pressure of 0.144 psi.

** Preliminary tests indicated that volume equilibrium of the compressed feathers was attained after about 1 minute.

*** Specific Volume is defined here as volume per unit weight of the material in CGS units.

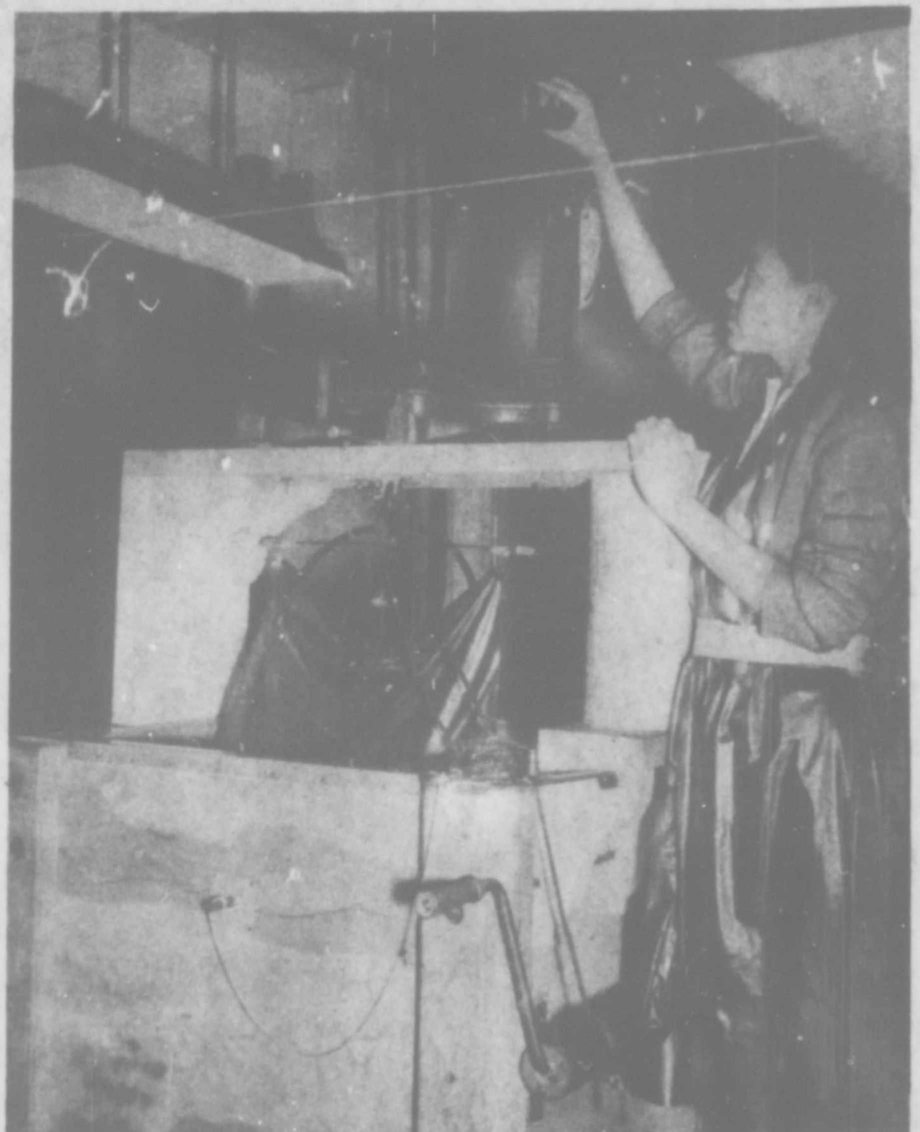

FIGURE 4

Hydrostatic Machine Shown in Use: The Submersion frame hanging from the Platform Scale hook has submerged the waterproof vinyl bag. This bag is shown with its top portion supported by two clamps. A venting tube reaching the enclosed pillow of feathers is shown extending out of the mouth of the bag. The Vinyl bag contains 1 lb. of feathers inside of a cloth pillow.

FIGURE 5

Box Method Shown in Use

Two pounds of feathers have been fluffed by hand in the box. After two minutes the operator is shown gently placing a light cardboard netting piston on these feathers. The height of the piston from the bottom of the box then remains to be measured.

Sampling and Testing Procedure. For the inclined-plane method, five separate samples each weighing 20 grams ± 0.1 gram were chosen at random from each lot of original and pounded feathers. Each sample was given three separate tests, each of which consisted of three compression-relaxation cycles, the results of each test being autographically recorded on one chart. The feathers were fluffed on a table before each test.

For the hydrostatic method, five separate one-pound samples randomly selected from each lot of original and pounded feathers were evaluated. Each sample was subjected to five separate submersion tests, after each of which the pillow of feathers was removed from the vinyl bag and thoroughly fluffed.

For the box method, two separate two-pound samples were taken at random from each lot of original and pounded feathers and each sample was subjected to two filling-power tests. This is referred to hereafter as the "first series" of tests.

Six months later it was decided to make a further investigation of the box method, and samples were drawn from untested feathers which during that period had been stored in boxes under some pressure. Five two-pound samples were chosen from each lot (pounded feathers had not been stored) and each sample was given 15 successive filling-power tests, being permitted to "relax" for one-half hour prior to evaluation by being spread and fluffed on a large table. Between each test the feathers were spread on the table for at least two minutes to permit relaxation.

An experienced feather expert was employed to rate the quality of the feathers and to analyze the percentage of physical components of each lot.

DISCUSSION

Results of Filling-Power Measurements. In Table 1 is given the feather expert's evaluation together with the analysis of each lot in terms of percentage composition and grading. The filling-power results obtained by each test method were averaged and converted to figures representing specific volume and a computation was made of the standard deviation for each measurement procedure* on each lot and treatment as shown in Table 2. In the case of the inclined plane data the values of specific volume were obtained by

* The standard deviation was not calculated on the box-method results on the first series because of insufficient data.

multiplying the filling-power results by a factor of 8.57* while the box-method results were converted using a factor of 10.4**. As explained above, the figures obtained by the hydrostatic procedure are directly expressed in specific volume units. In Figure 6 are plotted specific volume ratings as obtained by each method on each lot and treatment of feathers. In this figure the procedures are arranged in order of increasing pressures, the box method applying .0006 psi, the "Y" inclined plane .02 psi, the hydrostatic 0.1 psi, and the "X" inclined plane 0.22 psi.

Analysis of Data. Table 4 shows that the filling power of the various lots of feathers was rated in exactly the same order by the feather expert's subjective method and by the three objective procedures described above. From the filling-power values of Table 2 the specific-volume data of Table 3 was computed and plotted in Figure 6. These illustrate the greater sensitivity of the box method indicating that differences in filling power are much more easily detected when measuring at very light loads. Conversely, increasing the pressure on feathers tends to hide the relative differences in the feathers which are shown to exist at low pressures.

Not only is the box method more effective than the other methods studied in measuring differences in filling power from lot to lot, but this procedure is also much more sensitive to changes which occur in a given lot of feathers produced by pounding as is shown in Figure 7.

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* Specific volume = cubic centimeters per gram

$$= \frac{(\text{no. of c.c./cu. in.})\ (\text{filling power:in.})(\text{cylinder radius:in.})^2(\pi)}{(\text{weight of feathers:grams})}$$

$$= \frac{(16.39)\ (\text{filling power:in.})\ (1.825)^2\ (3.14)}{(20.0)}$$

$$= (8.57)\ (\text{filling power: in.})$$

** Specific volume = cubic centimeters per gram

$$= \frac{(\text{no. of c.c./cu. in.})\ (\text{filling power: in.})\ (\text{box side: in.})^2}{(\text{wt. of feathers: lbs.})\ (\text{no. of grams/lb.})}$$

$$= \frac{(16.39)\ (\text{filling power: in.})\ (24.0)^2}{(2.00)\ (453.6)}$$

$$= (10.4)\ (\text{filling power: in.})$$

TABLE 3

Specific Volume* Values of Various Grades of Feathers Before and After Dry Pounding Measured by Three Methods

Method	Test Pressure (PSI)	Hours Pounded	Specific Volume (cc/Gm) Lot A	Lot B	Lot C	Lot D	Lot E	Standard Deviation** (cc/Gm) Lot A	Lot B	Lot C	Lot D	Lot E
Box	.0006	0	170	139	220	75	200	None calculated for Box Method because of insufficient data				
		1½	145	107	185	63	157					
		6	142	102	175	60	155					
		10	114	95	173	54	142					
Inclined Plane "Y" Values	.018	0	20.9	18.3	24.1	13.7	21.3	0.80	0.56	0.51	0.46	0.55
		1½	20.0	17.1	23.8	13.0	20.6	.21	.30	.39	.24	.63
		6	19.3	15.9	23.8	12.5	20.1	.42	.15	.37	.31	.26
		10	19.2	15.8	23.5	12.0	19.2	.49	.39	.46	.17	.52
Inclined Plane "X" Values	.22	0	14.6	12.5	17.8	10.8	16.8	0.39	0.45	0.51	0.43	0.53
		1½	15.1	13.1	17.2	10.4	15.6	.09	.41	.45	.12	.32
		6	14.8	12.4	17.3	9.9	15.2	.00	.26	.34	.34	.19
		10	14.5	12.2	16.9	9.4	14.4	.05	.24	.36	.27	.35
Hydrostatic	.14	0	14.8	13.1	17.6	10.4	15.5	0.28	0.22	0.35	0.24	0.51
		1½	14.3	12.6	17.2	9.9	15.1	.23	.28	.46	.36	.54
		6	14.0	12.0	16.8	9.4	14.8	.46	.32	.34	.41	.47
		10	13.4	11.5	16.4	9.0	14.5	.23	.42	.26	.45	.53

*Based on Filling Power Values (Table 2) as follows:

Method	x	Factor	= Specific Volume
Box		10.4	
Inclined Plane		8.57	
Hydrostatic		1	(Filling Power obtained directly as Specific Volume)

For derivation of factors, see footnotes, page 12.

**The number of samples (N) tested for each lot and pounding time

Box Method	N = 2
Inclined Plane Method	N = 15
Hydrostatic Method	N = 25

Source: Results of tests performed at the Philadelphia Quartermaster Depot

TABLE 4

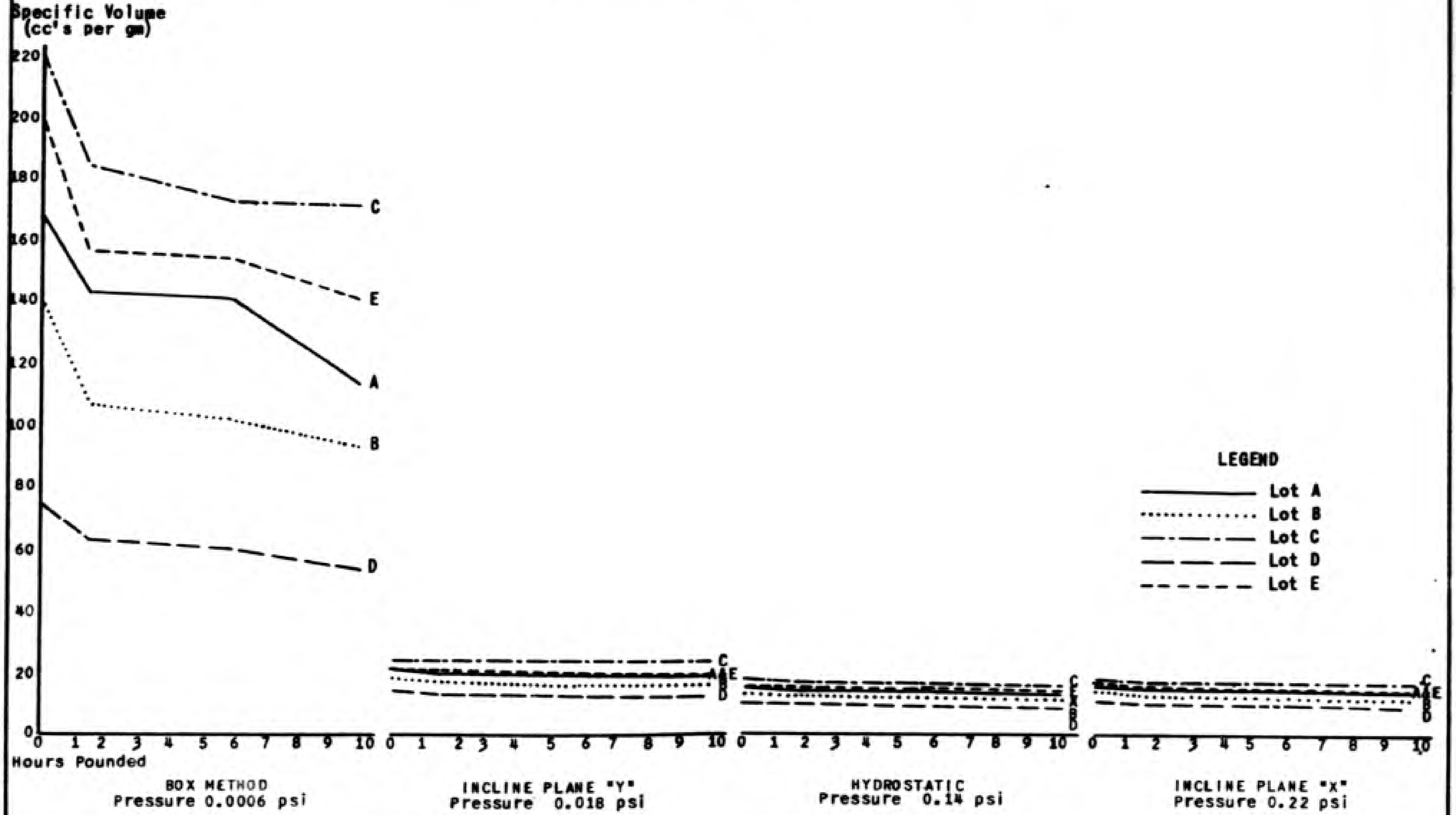
Relative Filling-Power Ratings of Original Feathers

Lot	Test Pressure (PSI)	C	E	A	B	D
Subjective Rating		Excellent	Very Good	Good	Fair	Very Poor
Relative Rating*						
by Zero Load Method	--	100%	95%	71%	67%	24%
by Box Method	.0006	100	90	76	62	34
by Inclined Plane "Y" Method	.015	100	89	87	76	57
by Inclined Plane "X" Method	.22	100	94	82	70	61
by Hydrostatic Method	.14	100	88	84	74	59

*Objective ratings, data of Table 2 expressed as percent of Filling Power of Lot C.

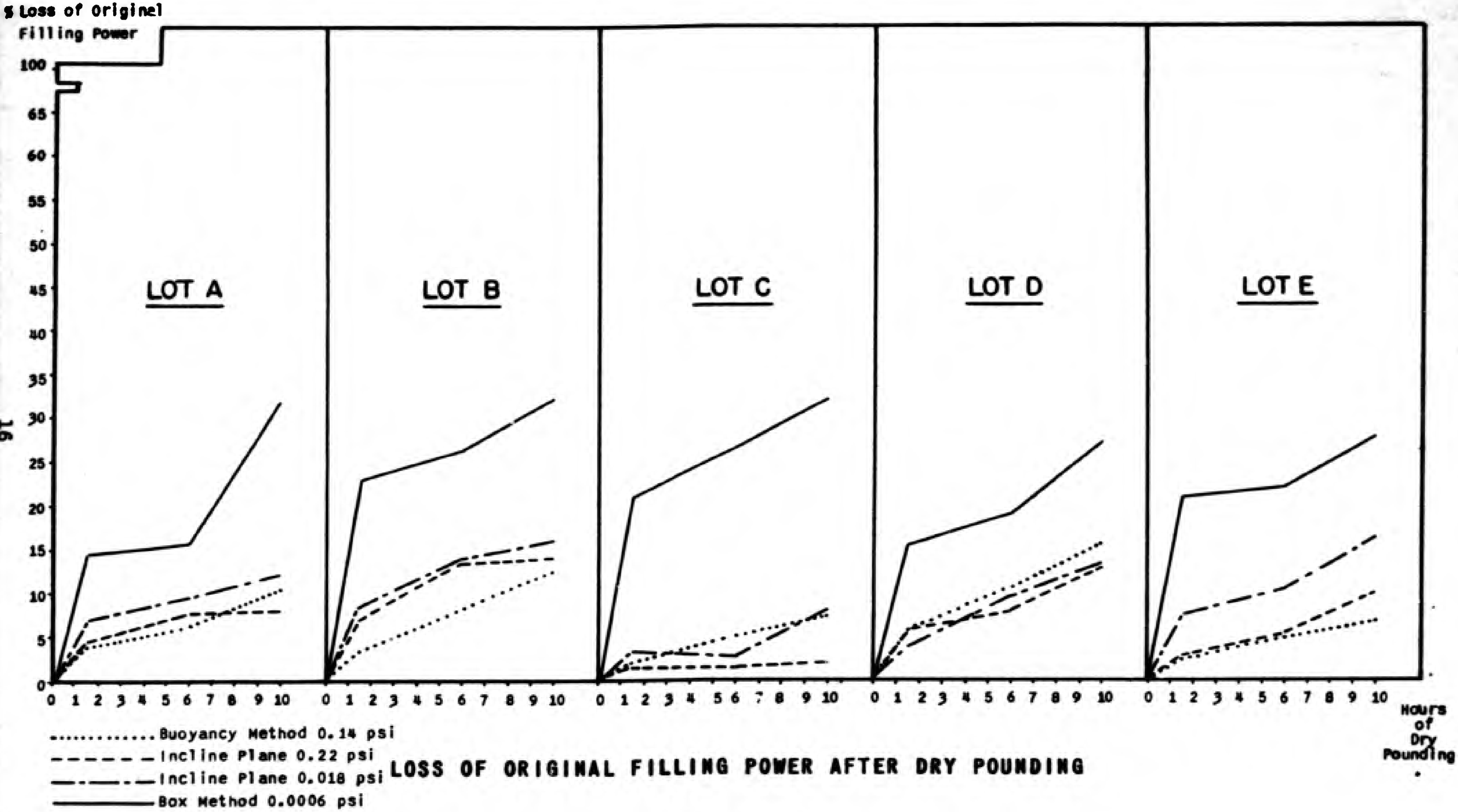
Source: Subjective ratings, Table 1

SPECIFIC VOLUME OF LOTS OF NEW AND USED FEATHERS BEFORE AND AFTER POUNDING
MEASURED BY SEVERAL METHODS AT DIFFERENT PRESSURES



Source: Table 3

FIGURE 6



LOSS OF ORIGINAL FILLING POWER AFTER DRY POUNDING

Source: Table 2

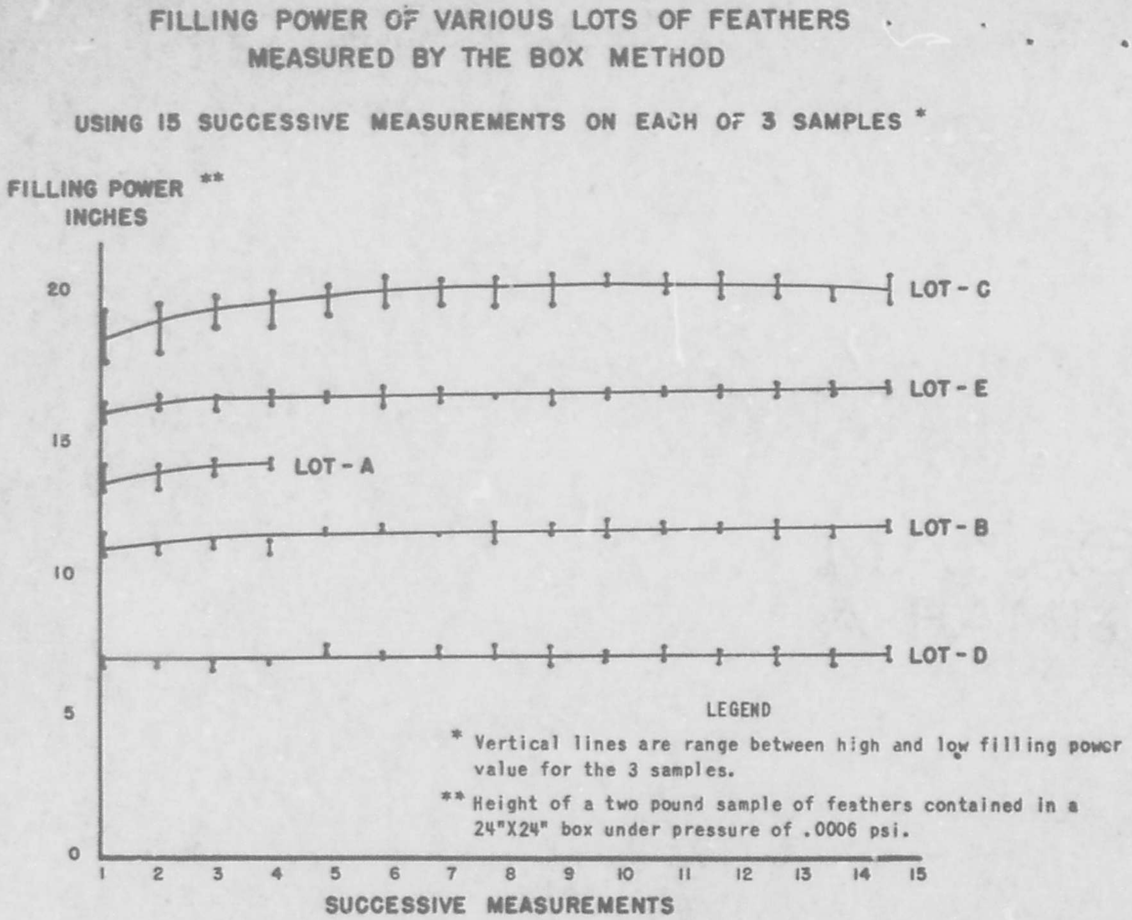
FIGURE 7

This first series of tests focused attention on the need for further information concerning the box method. Thus, while this technic was shown to have more than twice the sensitivity to small differences in filling power of either the inclined-plane or hydrostatic-machine methods, little information was available regarding its variability, which, if excessive, might easily vitiate higher sensitivity. For this reason a second series of box-method tests was undertaken. The results plotted in Figure 8 illustrate the fact that variability of the method is relatively small and in no case affects the large differences detected in filling power from lot to lot. Analysis showed that generally, a relative dispersion of 3% existed around the plotted curves. It seemed reasonable to assume, therefore, that the box method measured the filling power of a given sample of feathers with an accuracy of approximately 3%. The relatively high accuracy obtained by the box method is explained by the fact that a two-pound sample is used, whereas only a .04-pound specimen is required by the inclined-plane method and a one-pound sample by the hydrostatic method.

The hydrostatic method possessed three defects: (1) air tends to be trapped on the highly flexible (and crinkled) surfaces of the vinyl bag thus producing high buoyancy values and although gentle shaking of the pillow under water removed many of these bubbles, the agitation in itself introduced pressures on the feather mass which caused unpredictable compressions; (2) it was found difficult to center the pillow under the submersion frame, hence both pillow and frame tilted, resulting in pressure variations; (3) the method was untidy and difficult to perform.

The value of the inclined-plane method lies primarily in the autographic stress-strain diagram obtained and the control of loading rate. However, the adequacy of the sample size is open to question. In addition, the fact that approximately equal specific volumes (Table 3) are obtained for the same feathers under the varying pressure conditions of the hydrostatic (.14 psi) and inclined-plane (.22 psi) methods suggests two possible defects in the latter method: (1) friction of the piston against the cylinder and maldistribution of pressure within the sample, or (2) failure of the feathers to reach a state of bulk equilibrium.

To determine the pressures to which feathers lining the bottom of the sleeping bag are subjected by the sleeper, a mercury-filled thin-walled rubber bladder attached to a manometer was used as shown in Figure 9. Pressures were measured by placing the bladder under the sleeping bag at various positions along the body of the occupant and noting the height of the mercury column in the manometer. The results are plotted in Figures 10 and 11.



SOURCE: MEASUREMENTS MADE AT THE PHILADELPHIA QUARTERMASTER DEPOT.

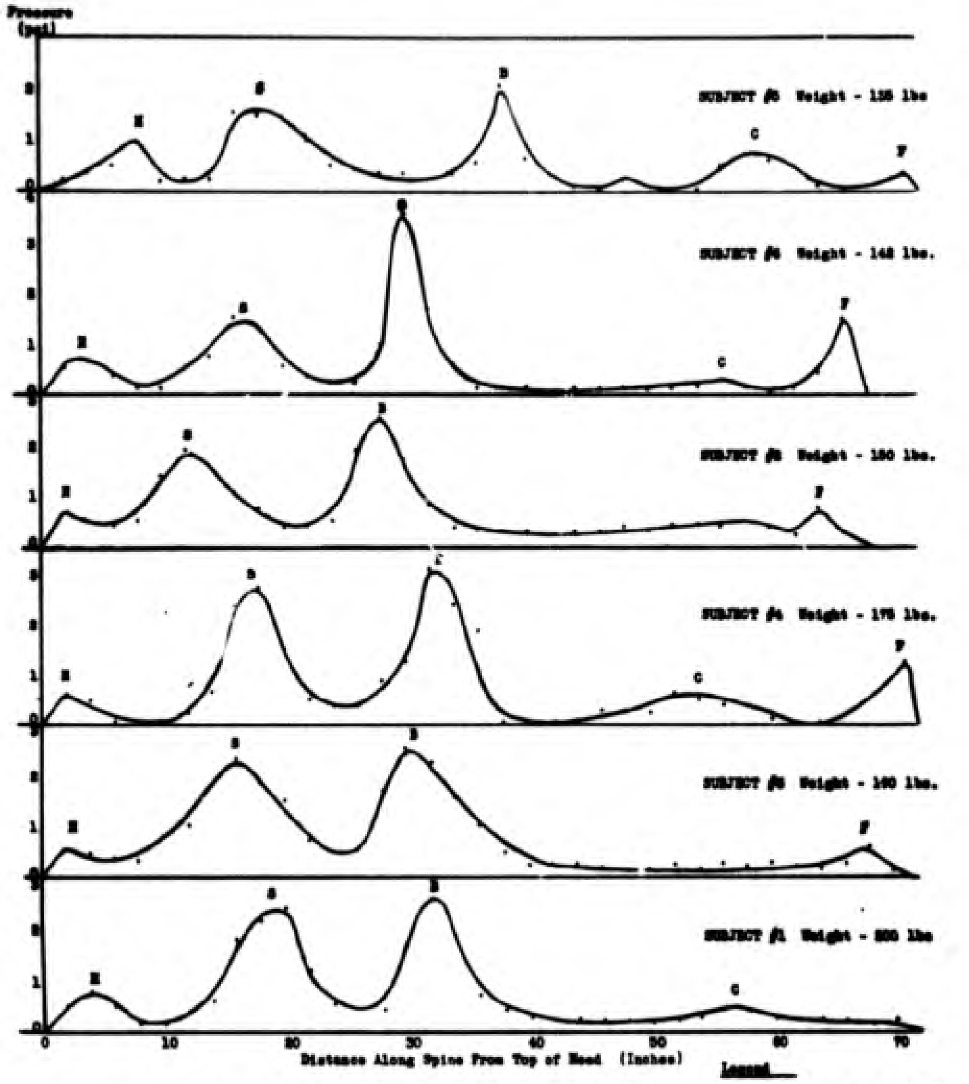
FIGURE - 8

FIGURE 9

Photograph of subject lying in sleeping bag showing manometer connected to mercury-filled rubber bag. Pressures were measured by placing the bladder under the sleeping bag at various positions along the body of the occupant and noting height of the mercury column in the manometer.

DISTRIBUTION OF PRESSURE ON THE BOTTOM OF THE SLEEPING BAG

(PRESSURE MEASUREMENTS ALONG SPINE OF SLEEPER)

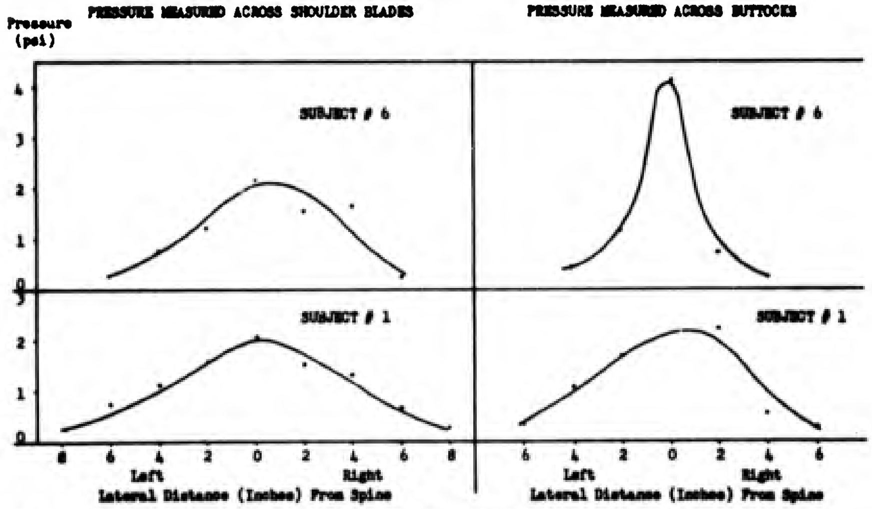


Source: Measurements taken at Philadelphia Quartermaster Depot.

FIGURE-10

DISTRIBUTION OF PRESSURE ON THE BOTTOM OF THE SLEEPING BAG

(PRESSURE MEASUREMENTS ACROSS SHOULDER REGION AND BUTTOCKS)



Source: Measurements taken at Philadelphia Quartermaster Depot.

FIGURE-11

It was noted that body protuberances at the buttock and shoulder regions exerted pressures on the bottom of the sleeping bag in the order of 3 psi but that the major area at the bottom of the bag sustained a load not exceeding 0.5 psi. The top and side of the sleeping bag, which are probably under very small pressures (near .001 psi), contribute in a large measure to the heat insulation afforded by the bag, and constitute by far its greatest area.

While these measurements were being made it was noted that motion of the subject caused pressures two to three times those observed when the occupant was quiet.

CONCLUSIONS

Optimum Method. The best method for determining the filling power of feathers, evaluated to date at the Philadelphia Quartermaster laboratory is the box method; i.e., one which uses a pressure of .0006 psi exerted on a two-pound sample of feathers fluffed into a large container. The load should be exerted for at least 20 to 30 seconds before measurements are made, although in the tests reported, a two-minute interval was used. Reducing the load to zero increases the sensitivity of the method to small filling-power differences, but this advantage is vitiated by the greatly increased variability in results. Conversely, increasing the pressure to .02 psi and higher markedly reduces sensitivity by 50% or more with but little decrease in variability. Extrapolation of data presented to permit prediction of filling power at 3 or 4 psi indicates that differences in all feather lots tend to disappear when such higher pressures are used. Use of a controlled atmosphere is desirable but experience shows that sufficient test accuracy in measuring the filling power of feathers is possible despite variations in temperatures from 75° to 90°F and in relative humidity from 40% to 85%.

Question exists as to whether the filling power of the sleeping-bag fill should be measured at those pressures encountered in use. Though an affirmative reply might seem logical, it appears from the information already stated that filling-power differences of feathers are at a maximum at very low compressions and practically cease to be of consequence at pressures of 3 psi or more. Since all the different grades of feathers tested approached asymptotically the same minimum filling power at these higher pressures, it follows that the most reliable evaluation of this quality should be obtained at the lowest test pressure consistent with accuracy, and that little is to be gained by the use of higher values of compression.

Accelerated Durability Test. The expectation that the new and best feathers would be less affected by pounding than old, presumably more dried out (brittle) feathers, was satisfied only to a limited extent by measurements taken by the inclined-plane and hydrostatic methods. The results of the box method, on the other hand, were entirely at variance with expectations. Thus it may be stated that the accelerated durability test described in this report is of little use in rating feather quality.

Pressure Distribution of Sleeper on Sleeping Bag. The top and sides of the sleeping bag are under "self" pressure of a low order estimated to be in the region of .001 psi. The sleeper produces pressures varying between 0.2 and 4.0 psi on the bottom of the bag, sample distributions being given in this report in chart form. During motion of the occupant, pressures from two or more times as severe as those recorded may occur.

Extrapolation of Results to Include Other Filling Materials. These conclusions are applicable to feathers and cannot be extrapolated to cover other types of materials such as kapok, cotton, wool, or synthetic fills. The durability test has already demonstrated that excessive "balling" takes place in pounding certain synthetic fills of a fibrous nature. However, results of tests on these materials are as yet too meager to warrant their inclusion in this paper.

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