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THE EVALUATION OF EXPERIMENTAL FABRICS AS ALTERNATES FOR STANDARD WOOL FABRICS

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SUMMARY

1. The nature of the fabric surface - its hairiness or smoothness - is shown to influence a variety of fabric properties associated with warmth and comfort. A fuzzy surface tends to make a fabric more resistant to transfer of liquid water and increases its thickness and thermal resistance. A number of methods for quantitatively characterizing the fabric surface are in process of development. These include (a) a photographic technique, (b) a method using the rate of cooling of a small metal disc in contact with the fabric and (c) thickness-pressure measurements at low pressures. With the first two methods, it is possible to estimate the number of surface hairs and their length; with the last technique, a parameter may be calculated which correlates well with subjective judgements of handle.

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2. Wicking tests have been made on a series of blended serges by a longitudinal method and by a drop absorption procedure. Generally, the introduction of any non-wool fiber increases the wicking speed substantially. Of the various blends studied, a sample containing 30% Dacron wicked most slowly and a blend containing 30% Vicara and 20% nylon ranked second in this regard. Yarn twist is shown to exert an important effect in wicking. Experiments with rovings of nylon and of wool indicated that the wicking rate increased rapidly with increasing twist. With viscose rovings, wicking was rapid and not greatly influenced by twist until very high twist was introduced; the latter effects a marked slowing of wicking and it is shown that this can be accounted for by the swelling of the fibers.

3. A series of seven commercial tropical suitings was subjected to a battery of laboratory tests to evaluate them for wear in hot climates. These included a group of tests to measure: a) Comfort - weight, thickness, thermal resistance and air permeability, b) Appearance - drape, crease and muss resistance, perspiration fastness and shrinkage and c) Miscellaneous factors - handle and stiffness. A number of samples were found to be equal to or better than the standard tropical fabric in each of the categories with respect to the laboratory tests for use in warm weather areas. Among the 7 fabrics studied, a sample containing 90% wool and 10% nylon appears to rank highest in desirability in all categories of tests; other fabrics probably quite suitable include blends containing viscose and acetate, so that the opportunity for conservation of wool in this type of fabrics appears to be good.

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DETAILS

I. Wicking.

A. Introduction.

The wicking behavior of fabrics is being studied intensively with respect to the physiological aspects at CRL and with emphasis on the fabric property at PQD and in these laboratories. Previous work with serges and coverts has suggested that the use of synthetics in a blend with wool tends to promote wicking and that of the various blends available, those containing viscose wicked most rapidly. In addition to the nature of the fibers involved, other factors such as construction and finishing may markedly alter the wicking behavior. A test which has been used both at PQD and in these laboratories is the longitudinal wicking test which measures the time for water to rise in a vertical strip of cloth. Since many use conditions involve transverse transfer of liquid, some attention was given to a simple method for studying this property.

B. Transverse Wicking.

A simple test procedure that showed some promise, involved the measurement of the time required to absorb a small volume of water placed on the surface of the sample in a horizontal position. Trial experiments indicated that a suitable volume was 0.2 ml. and that the end-point could be fairly sharply estimated by the disappearance of a reflecting liquid layer of water. This test was thought to simulate the use condition in which an outer water resistant garment begins to leak dropwise at the seams, the fabric underneath being subjected to small droplets of water. The drop absorption test was performed on the series of NRC blended serges for which other wicking measurements were reported previously, the results being shown in Table 1.

In group A, the addition of 30 percent of Dacron results in an appreciable decrease in absorption time. With all of the other synthetic blends, the drop absorption rate is extremely rapid. While differences of a factor of two are statistically distinguishable by this test (e.g. fabrics 746 vs. 747 or 747 vs. 741), it is believed that in terms of the use situation a linear scale of wicking speed is not appropriate. Adoption of this point of view would result in classification of the group A serges into very slow wickers (all wool), moderately slow wickers (Dacron blends) and very rapid wickers (blends containing Orlon, Viscose and Chemstrand). In group B, the acetate-nylon blend wicks very rapidly, the Dynel blend somewhat more slowly and the Vicara ternary blend begins to approach the moderately slow water absorption behavior of the Dacron blend, especially after napping. The all nylon and all cotton serges in group C absorb water extremely rapidly.

The data in group D are reported to emphasize again that caution is required in interpreting wicking results as dependent on fiber content only. The four fabrics in this group are all specification serges differing quite markedly in wicking behavior, despite the fact that all test specimens were laundered prior to test with the view to bringing them to a "standard" surface condition. The samples grouped together in the upper part of Table 1 (groups A and B) are considered as reasonably comparable since a single lot of wool was used for blending and all the fabrics in a group were made in the same mill.

While the drop absorption test was developed on the basis that it would emphasize wicking through the fabric surface, the results correlate well with the longitudinal wicking tests given in the previous report. The relationship is shown in Figure 1, using a log-log plot to accomodate the several cycles of log time involved.

C. Factors Other Than Fiber Composition Influencing Wicking.

1. Yarn Twist.

In the previous report, it was shown that of various construction factors studied, the yarn twist appeared to affect the wicking most markedly. It was decided that some further quantitative study of this phenomenon was warranted. Slivers of top were available which were made of viscose, nylon and wool of both long and short staple. These were carefully scoured by hand and water rinsed. Rovings of roughly equal weights were then removed from the sliver disturbing the parallelism as little as possible and longitudinal wicking tests were run after inserting varying amounts of twist into the roving. The wicking times as a function of twist are shown in Table 2.

Both nylon and wool respond to twist in the same sense, the wicking time decreasing with increasing twist. The nylon at 5 tpi wicks considerably more rapidly than either of the wool samples. The results with nylon and wool are readily understood in terms of the change in capillary size with twist. That is, as the twist increases the dimensions of the capillaries decrease which would be expected within certain limits to increase the rate and extent of wicking.

The viscose roving, on the other hand, exhibited a remarkably different pattern of behavior from the other fibers. The wicking was quite rapid in the range 1/2 to 5 tpi and in fact the rate tended to decrease slightly in this range. On introducing additional twist above 5 tpi however, the wicking time increased by an extremely large factor as shown by the value at 9 tpi in the table. While the result is rather surprising it may be explained in terms of the swelling of the fibers by the liquid resulting in the reduction of the number of capillary spaces or of their size, such that the amount of water transported is small. This is essentially the same principle used in Shirley cloth for water repellency. That the swelling of the fibers is responsible for the phenomenon in this case was verified by subjecting the viscose to a typical formaldehyde cross-linking treatment. The latter is known to decrease the swellibility of the fibers, and the wicking speed is also seen to be greater for the treated viscose at high twists.

In general therefore, if it is decided that slow wicking is a desirable characteristic of fabrics, the data suggest that this may be achieved through the use of low twist yarns in the case of fibers which do not swell excessively; with a fiber like viscose, a very high degree of twist may be used to the same end.

2. Previous History.

One of the problems encountered by workers in the field of water repellency has been that the type of processing prior to finishing or testing exerted a considerable influence on the result. Thus even traces of residual wetting agents and salts from scouring and dyeing can make it difficult to make a fabric adequately water resistant. A similar effect is observed with respect to wicking, and an example was cited in Report No. 1. Three laundered all wool fabrics (A, H and K) in group D of Table 1 have been shown to differ widely in their wicking behavior despite similarities in their general construction and appearance. The reasons for these differences were sought in the possible differences in the residual non-fiber materials present. Accordingly, samples of these fabrics were extracted in hot ethanol, ether and water (in this order) and the wicking determined at the same time before and after extraction.

The results, given in Table 3, indicate that the rapid wicking of sample K may indeed be associated with the presence of extractable materials which promote wetting since extraction increases the wicking time tenfold. The results with sample H do not appear to fit this explanation at all and efforts at determining the cause for the rapid wicking are continuing. One possibility lies in the yarn twist since preliminary measurements suggest that the singles yarns of sample H are more highly twisted.

3. Nature of the Surface.

Results in Table 1 (group B) and in the previous report suggested that napping was effective in decreasing the wicking rate of some fabrics. In view of our interest in the fabric surface, measurements were made of fabrics which had been napped or sheared in the laboratory to deliberately alter the character of the surface. The wicking behavior was determined by the longitudinal as well as the drop absorption methods, the data being given in Table 4.

These results illustrate an important respect in which the two kinds of tests may provide different information. In a number of cases, e.g. nylon serge, napping results in a fabric which wicks slightly more slowly as judged by the longitudinal results whereas the drop absorption test suggests a many fold decrease in wicking rate. From the test conditions it is clear that the longitudinal test minimizes the effect of the surface in that a cut edge is available for penetration of liquid and the head of water effective for forcing liquid through the surface is also greater.

With respect to the drop absorption test, napping is almost always effective in decreasing the rate of absorption substantially, the notable exceptions in the table being the all cotton serge and the Orlon blend. Conversely shearing effects a decrease in time for absorption.

In general, therefore, it may be concluded that wicking is affected by the nature of fiber, the fabric construction and finish and the presence of residual extractables. The present data suggest the following generalizations:

1. Blending of synthetic with wool results in more rapid wicking; in the series of serges currently available Dacron affects the wicking of a blend less than do other synthetics. The ternary blends containing Vicara and nylon tended to wick relatively slowly.

2. For many fibers, low twist yarns will reduce the rate of wicking materially. This is not the case for viscose, for which very high twist yarns may hinder wicking.

3. Napping tends to reduce the wicking rate transversely through the fabric surface for many types of fiber.

4. Residual extractables from wet processing (probably wetting agents) may increase the wicking rate considerably. The contribution of this factor to the overall wicking may however be expected to diminish with use and laundering.

II. Thermal Resistance of Fabrics.

A. Effect of the Nature of the Surface.

In Report No. 2, it was observed that serges made of nylon and of cotton exhibited much lower values of specific thermal resistance when measured at thicknesses corresponding to pressures of 1.0 lb/in^2 than did other fabrics of generally similar types. It was suggested that this could be explained either by the relative smoothness of these fabrics or by the high specific conductance of these fibers. Some experiments have now been done which tend to confirm the former hypothesis.

The thermal resistances of specimens of nylon and of cotton serge have been determined with a controlled pressure thermal transmission apparatus before and after napping; the results are reported in Table 5. It can be seen that napping increases both the thickness and the thermal resistance of the fabric but that the resistance increases more rapidly than can be accounted for by thickness alone; this latter effect is seen in the increasing specific resistance values (thermal resistance per inch of fabric thickness) as napping progresses. The mechanism may be thought as involving more effective thermal transfer for the smooth fabrics as the number of surface fibers making contact is greater and the conducting paths are shorter.

These results clearly illustrate the effect of the nature of the surface on the warmth properties of fabric. They indicate that for a given thickness of fabric better insulation is obtained with a fuzzy than with a smooth surface. It is interesting to note that the specific resistance values of these two samples begin to approach the thermal resistance of the blended serges containing 70 percent wool.

It appears possible, therefore, to enhance the insulating power of basically smooth structures by some kind of napping process. One of the advantages of wool-containing fabrics may be in the inherent ease with which fuzzy fabrics are made with or without the intervention of a napping process. This fuzziness is invariably enhanced by fulling and by the felting occurring in wet processes in which fibers migrate in a random manner out of the yarn structure.

B. Wet Thermal Measurements.

Work is in progress on the construction of an apparatus which will permit the study of the more complex situation arising when heat is transferred across a fabric from the sweating skin under varying condition of wind velocity. Certainly in respect to tests on alternate fabrics we are at a loss to predict their "heat with moisture" insulating properties without measurements of this kind. A review of the literature on this subject has indicated that there are quite a number of ways in which measurements of this type can be carried out. The design of the apparatus to be discussed has been based upon the experience of these investigators as well as on previous work carried out in this laboratory.

Almost all the methods used for studying the simultaneous transfer of heat and water through clothing materials have involved the simulation of the skin of a sweating man on which the clothing to be tested is placed. The "sweating" surface for this apparatus is a three inch diameter semi-cylinder of porous stainless steel. Means are provided for attaching the fabric to be tested to the curved surface of the porous cylinder and the whole placed in a laminar air stream normal to the base of the semi-cylinder. Water, thermostatted to 33°C., in a reservoir attached to the base of the semi-cylinder is forced through the cylinder's surface at a rate sufficient to keep the underside of the fabric wet. The most suitable temperature, rate of water efflux, and size of curved surface have been arrived at from studying the results of physiological investigations of this type.

From a knowledge of the temperature and humidity of the air stream directed at the fabric surface, thermal and moisture gradients across the fabric may be defined for any wind velocity. A balance is used for following the change in weight of sweating surface and attached reservoir. Hence the loss of moisture per unit time through each fabric can be determined. An integration of the electric power supplied to heat the reservoir in a period of time with a watt-hour meter allows one to calculate the heat loss through the fabric for each setting of the heat and moisture gradient. By placing the sweating surface and heat reservoir in the throat of a wind tunnel of conventional design, studies in which air velocities are variable from zero to 20 miles per hour will be possible. Because the "sweating" surface forms an integral part of the hot water reservoir it will be possible to carry out heat transmission runs without having the fabric wet, in the usual sense, but at high relative humidity. This type of experiment should correlate with those performed on the Cenco-Fitch heat transmission apparatus which has already been described.

In summary it might be said that this form of "wet-heat" testing is designed to provide general information regarding the comparative effectiveness of fabric types as insulators to heat and moisture. At the same time provision has been made to obtain the information necessary for studying the mechanisms by which heat and moisture transfer takes place and the role the various fabric characteristics play in this complex process.

III. The Nature of the Fabric Surface.

A. Photographic Method.

In the last report, there was presented a method for evaluating the nature of a fabric surface which consisted in enlarging a photograph of the edge of a folded specimen. While this method involves the making of subjective judgements of hairiness it has proved very useful in rating the fuzziness of test underwear fabrics to be used in physiological experiments at CRL; a good deal of work along these lines has been done indicating the desirability of fulling and/or scouring for increasing the hairiness of nylon or cotton underwear. A pair of samples illustrating the effect of scouring on cotton underwear is shown in the photograph attached to this report, sample 72 being unscoured and sample 66 that after scouring for 2 hours.

In an effort to arrive at a more quantitative basis for evaluation of surface hairiness, a grid was photographed simultaneously with the sample. In the photographs reproduced, the sides of each small square correspond to lengths of 6 mils. It was believed that a simple counting method might be used to define the surface fuzziness. After some trials, the method tentatively adopted was the following:

1. A base line was drawn representing the upper limit of the base fabric or the lower effective limit of the fuzz fibers. Because of the undulating pattern of the base structure this is not a simple matter; however, it was reasoned that the fibers in the hollows did not contribute to the overall hairiness and hence the base line was always drawn tangent to the peaks.

2. A series of parallel grid lines was ruled corresponding to 6 mil distances on the fabric. The number of fibers intersecting each grid line was counted over a horizontal distance corresponding to 240 mils on the fabric surface. A typical distribution for the three all wool fabrics (A, A-napped and 13) reproduced in the photograph is shown in Table 6 as well as some typical calculations.

It may be assumed that the number of intersections made with the first grid line above the base represents the total number of surface fibers in a distance of 240 mils that are longer than 6 mils. The sum of the product of 6 by the total number of intersections may be used to represent the effective total length (distance between ends) of all of the surface fibers i.e., approximately the total length of a single fiber made by placing all the fibers end to end. If the number of intersections at the third grid line represents the number of fibers 18 mils or longer, then the ratio of this number to the number at the first grid line is a measure of the number of long fibers. These calculated parameters for three types of cloth do indeed appear to relate to the visual impression given by the photograph. It is intended to pursue this type of measurement further on a graded series of fabrics and to relate it if possible to the other methods of evaluating the surface character of materials.

B. Hot Penny Method.

Previous reports have described the so-called hot penny technique for evaluating the surface character of fabrics. By determining the rate of cooling of a small metal disc (initially at an elevated temperature) placed in contact with a fabric at room temperature it has been possible to describe the surface in terms of n (number of fibers per sq. cm.), l (length of fuzz fibers) and k (specific conductance of the fiber substance). For those interested in the detailed derivation of the equations, the theory employed and the assumptions made, an appendix to this report has been prepared bringing this material conveniently together.

In order to test the method additional runs have been made on samples of fabrics in which the surface character has been altered by napping or shearing. In addition to the t1/2 values as used in the previous report (time to cool the hot penny 7.5°C.), the ratios of the number of surface fibers to their length (n/l) were calculated substituting values of fiber conductance from the literature in the equation (appendix to this report). In addition to measurements at approximately 0.1 lb/in.^{2} between fabric and disc, data were also made at the self-pressure exerted by the weight of the specimen alone; this latter pressure corresponds to approximately 0.0021b/in ^{2}. The results are given in Table 7.

The following generalizations appear possible from these data:

1. Napping results in an increase in the time for cooling indicative of the smaller number of fibers contacting the heated disc or of greater length of fuzz; hence the n/l ratio decreases with napping.

2. Shearing affects a fabric in an opposite manner, the hot penny cooling occurring more quickly as a result of either more fiber contacts or shorter fuzz height; the calculated n/l ratios are correspondingly greater for the sheared fabrics.

3. The rate of cooling of the hot penny is lower at the lower pressure and this is explainable in terms of fewer fiber contacts and longer surface fibers· hence n/l is found to be lower at self-pressure than at 0.1 lb/in ^{2}. This is discussed further in the next section of this report.

It appears that the hot penny data reflect in a sensible manner the changes in surface fiber contacts produced by finishing or by compression of the surface. A pair of rayon fabrics otherwise identical, one sample made from filament and the other from staple fiber were tested by the hot penny technique. These were obviously different in surface character (see section IV of this report for compression data); the hot penny results clearly reflect this difference, the staple fabric making poorer contact (lower n/l) than the filament.

It is to be noted that since the calculation of n/l involves the use of fiber conductance values, it is not feasible to compare fabrics of differing fiber content due to the considerable disagreement in the published values of conductances. For fabrics of similar fiber composition however, e.g. 13, A and HB in Table 7, the relative magnitudes of n/l are comparable. In fact these values do arrange these fabrics in proper order with regard to visual and factual estimates of the number of fiber contacts and their length.

C. Variation of Surface Contacts with Pressure.

The earlier measurements with the hot penny method given in previous reports involved the use of a specimen loaded to a pressure of approximately 0.1 lb/in^2. Since many of the use situations involve lower pressures, attempts were made to carry out these measurements at lower loads. The data in the previous section show that this was feasible for many types of fabric. A series of hot penny experiments was performed at a range of pressures to determine what the n/l relationships were as a function of pressure. These data are shown in Table 8 for 4 fabrics.

These results suggest that an inverse functional relationship does exist between the rate of cooling in the hot penny method and the pressure; that is, as the pressure decreases, the fabric makes contact with fewer and/or longer fuzz fibers (n/l decreases). Graphs in which 1/n is plotted against the pressure are shown in Figure 2 and it is clear that the curves have the same form as the thickness-pressure curves. In order to illustrate this more clearly, the compression curve for one of the samples is inserted on the graph for comparison using an arbitrary thickness scale. The possibility exists therefore for relating hot penny data to that obtained from compression measurements This should aid considerably in interpreting the compression measurements in terms of the surface parameters, n and l. It is intended to pursue this line of attack further.

IV. Thickness - Pressure Relationships.

A. Introduction.

The previous report has discussed the possibility of characterizing fabrics in terms of a simple functional relationship: $t = a + b/(p + c)$, in which t and p are thickness and pressure, respectively, and a, b and c are constants. By means of this "equation of state" it is possible to estimate the thickness at any pressure over the range 0.002 to 2.0 lb/in^2 with good precision. The constants appear to be a potentially satisfactory means for characterizing a fabric; a represents the limiting thickness of the basic fabric structure at higher pressures; b or some function of b and c describes the compressibility characteristic of the fabric at low pressures and may be related to the nature of the fabric surface, its fuzziness and degree of contact with the skin.

B. Surface Character and the Thickness - Pressure Function.

Some additional work has been done on simpler means for estimating the constants in the above equation. For the group of fabrics studied, a may be satisfactorily estimated graphically by plotting the thickness values at the higher pressures against log pressure and extrapolating to $p = 10$ lb/in.^{2}. It was found that b and c vary linearly for any given fabric if a value of c is chosen arbitrarily within reasonable limits. This makes it easier to obtain b values readily for comparison of materials. A suitable value of c for the group of fabrics tested was found to be 0.05. Using this value for c and a graphical estimate of a, one can calculate a value of b from the product, $(p + c)(t-a)$, for each point in the compression curve. Averages of b calculated for pressures lower than 0.1 lb/in^2 for a number of fabrics obviously different with regard to surface character are shown in Table 9.

The first group of four serges in this table are samples for which the surface character has been described based on the surface photographs reproduced in the previous report. The values of b, in Table 9 are seen to decrease in regular order as the visual impression of hairiness decreases.

The next three pairs of serges constitute a homogeneous group of NRC fabrics for comparison; each pair comprises identical blended serges, except that one member of the pair has been napped on one side. The napping would be expected to enhance the fuzziness of the fabric surface and this is reflected in each case by a corresponding increase in the magnitude of b. The effect of napping will be discussed at greater length later in this report.

A pair of rayon lining fabrics was tested in this series, one sample being made from filament and the other from staple fiber. The staple fabric as judged by handle and visual inspection was obviously fuzzier and the value of b is again indicative of this subjective characterization. The very smooth completely non-hairy rubber sheeting exhibits compressive behavior corresponding to very low b values.

In general, therefore, the use of the thickness-pressure relationship noted above permits the calculation of equation constants which are useful for the description of fabrics and that in particular the constant b (at pressures 0.1 lb/in^2 and lower) is characteristic of the surface hairiness of the cloth.

In order to test the correlation of b values with subjective ratings of handle a series of 7 tropical weight suitings was used. Subjective judgements were made by a panel of observers who were asked to rate the fabrics in order of smoothness to fuzziness. It was found that when only 2 or 3 specimens were offered for judgement at any one time, the observers could make a decision quite readily and in surprisingly good agreement with one another; when more than 3 specimens were offered, the consistency of judgement suffered markedly. In addition it was found extremely helpful to space individual judgements at intervals of not less than one hour. It is interesting to note that when three samples were offered for evaluation, the common practice appeared to be the selection of 1 specimen as being "obviously" roughest or smoothest in the group, followed by slightly more mature discrimination of the remaining closer pair. The average rankings of subjective smoothness or hairiness are shown in Table 10 together with the b values calculated from the compression data.

The subjective rankings are seen to relate very well with the parameter b calculated from the thickness-pressure data; the rank coefficient of correlation is + 0.88. It can be concluded therefore that the constant b can be used to discriminate rather fine differences in smoothness or hairiness among fabrics and such an objective method for this purpose may be of general utility in the textile field.

Some thought has also been given to the possibility of relating the geometry of the fabric surface (fiber density, fuzz height, fiber fineness) and the mechanical properties of the fibers (modulus or stiffness) to the constants in the compressibility equation. This is a fairly complex system for analysis since it involves assumptions as to the mechanism of deformation of the surface fibers and with regard to the distribution of fibers on the surface at various thicknesses. Some preliminary experiments were made in which fabrics were either sheared or napped in the laboratory and the values of b calculated as above; the data are given in Table 11.

In line with the previous results, shearing effects a decrease in b and conversely napping results in an increase in b, and this is of course in agreement with the subjective evaluation of hairiness. Since each pair of fabrics in the table is identical except for the "finishing" process, the surface fiber fineness and stiffness are the same and the only effect due to napping or shearing may be in the number of surface fibers and their lengths. It is intended to compare estimates of the surface character obtained from compression data with those obtainable in other ways (viz. hot penny and visual methods discussed elsewhere in this report) in order to find whether a quantitative relationship may be deduced.

V. Evaluation of Tropical Fabrics.

A. Introduction.

A series of seven commercial tropical weight fabrics were submitted for physical evaluation of the fabric characteristics. It is understood that garments made from these samples are undergoing field trials at warm weather stations but no results were available to us at this time. The samples were given a commercial dry cleaning after being wet out in water for relaxation of processing tensions. The fabrics were then subjected to a battery of tests which may be grouped into three broad categories: (1) Physical factors influencing comfort, (2) Factors relating to the appearance in use and (3) Factors possibly affecting the psychophysical reactions of the wearer. This division is of course somewhat arbitrary and some degree of overlapping may be found. Such a grouping is however convenient for purposes of weighting the results for an overall evaluation. The results of measurement and the nominal fiber content of these fabrics are given in Table 12.

B. Comfort Factors.

The properties grouped in this category include weight, thickness, thermal resistance and air permeability. In contrast with the cold-weather fabrics examined previously, the emphasis in this group is on minimum warmth, weight and thickness and maximum air permeability. While it is obvious that these properties show interaction among themselves there is not complete one to one correspondence on the results shown in the table. In this group of samples, sample D, a wool nylon blend is lightest, thinnest and shows the lowest thermal resistance. One of the all wool fabrics, B, is heaviest, thickest and is the warmest sample in the group. Air permeability which is influenced strongly by structure is greatest with the viscose-wool blend C and lowest for two of the all wool samples B and H.

In order to compare the samples, the fabrics are arranged by rank in Table 13, a low rank being associated with a desirable magnitude viz. low weight, thickness and thermal resistance and high permeability. In order to avoid overweighting any given sample on the basis of small difference, the values for each property were grouped into a relatively small number of classes - 3 or 4 - as shown in Table 13. The sum of the ranks is also given in this table, a large number (maximum possible = 13) indicating an undesirable fabric and conversely for a small number. In this way, the order of preference among these fabrics with respect to their "comfort" properties would be D, C, (A, E, F, H) and B, the parenthesis indicating that differences among the fabrics enclosed could not be assessed.

C. Appearance Factors.

In this category, the tests included measurements of bending length by Peirce's hanging heart method (to evaluate drape), crease recovery at 65% R.H. with the Monsanto tester, crease recovery of moist fabrics and a muss resistance test developed in these laboratories. The wet crease recovery test consisted in placing the folded specimen for 15 minutes under load between blotters moistened to hold 150 percent water, after which the crease recovery in 5 minutes was determined in a standard atmosphere at 65% R.H. The warp and filling values were significantly different in several cases and in order to show this they are reported separately rather than as averages. The muss resistance test involved tumbling of small specimens in a rotating jar containing rubber stoppers and moist sponges and judging the samples visually with respect to the development of muss and creased areas. Fabrics were also tested for perspiration fastness by the AATCC procedure and for felting in a mild laundering procedure. The purpose of the latter was to determine whether in use in hot climates, felting would occur under the arms or in other areas subjected to wet mechanical action,

With respect to the test values in table 12, all of the fabrics may be considered as similar with respect to bending length, perspiration fastness (all excellent) and felting shrinkage. The blends containing 40 percent or more of viscose, A, C and F, exhibit poorer crease recovery than the other fabrics. Sample F is different from the others in that its wet crease recovery is good fillingwise and poorer in the warp direction. This may be due to the fact that the acetate content of this fabric is entirely in the warp yarns. While general agreement between the muss test and crease recovery has been obtained in the past, the correlation, especially with respect to the position of sample A is not good. This may possibly be accounted for in terms of the differing conditions of moisture and of the magnitudes of the deforming loads in the two test procedures. The sum of the relative ranks given in Table 13, indicate that with respect to all of the appearance-in-use factors, sample C (80% viscose) is poorest, sample A (50% viscose - 50% acetate) is intermediate and the remaining samples are classed best in the group. If the mussing test relates to the use condition more nearly than the sharp angle crease recovery tests, sample A which contains no wool would be expected to behave very satisfactorily in this regard.

D. Psychophysical Factors.

A group of observers was requested to judge these samples with respect to softness or harshness of handle and on separate occasions with regard to smoothness or hairiness. As discussed elsewhere in this report, when the number of specimens offered for ranking was kept small (3 or less) on each occasion and the offerings were separated in time, the judgements were surprisingly reproducible. The correlation between parameters calculated from compression measurements and smoothness or fuzziness is described elsewhere. It is also of interest that the evaluation of the order of softness and of smoothness were different in many cases. The resulting ranks are given in Table 12 and are also entered in Table 13 for convenience. These factors are considered of importance in the subjective prejudices of observers; there is a tendency to prefer smooth fabrics for warm weather clothing and soft fabric may have better "sales appeal". There is no consistent relationship between fiber content and these subjective judgements; three of the high wool containing samples are high on the softness list whereas another all wool sample is judged as harshest.

With regard to flexural rigidity, the fabric weight influences this considerably. It is felt that a stiffer fabric may be preferred in that it may not touch the skin and cling so much as a sample with lower flexural rigidity. This fabric property was given a small weight in the rankings in Table 13. The overall rankings of this group of properties indicates that sample D would be preferred, that next in order would be samples A, H, C and B and that the most undesirable group would include samples F and E.

In summing up the overall judgment of the suitability of these 7 fabrics for tropical dress uniforms therefore, it is concluded that the following order may be set down:

1. Comfort Factors - D, C, (A,E,F,H), B.
2. Appearance Factors - (B,D,E,F,H), A, C.
3. Psychophysical Factors - D, (A,B,C,H), (F,E).

Sample D, 90% wool - 10% nylon, appears to be most desirable in all three categories. The other fabrics are more difficult to rate since the relative weights to be given each of the contributary factors are not clear. If it is assumed that comfort and appearance factors are equally important then the group composed of samples E (wool), F (quaternary blend containing 40% mohair) and H (wool) may be next in order of desirability. If the mussing test is more appropriate than crease recovery for rating the appearance in use, sample A (50-50 viscose and acetate) would appear higher in rank of suitability.

The results of field trials and wearer ratings are being awaited with considerable interest for comparison with the laboratory tests just discussed.

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Appendix to Report 3

Theory of the "Hot Penny" Method for Determining Surface Contact in Fabrics.

Consider a copper disc of specific heat c, cross sectional area, A, and mass, M, at a temperature T (greater than ambient temperature, T_1). Suppose it to be thermally insulated so that no heat escapes from the sides or bottom of the disc. Then the flow of heat H, upwards from the disc as a function of time, t, will be

$$\frac{dH}{dt} = -Mc\frac{dT}{dt} \qquad (1)$$

If a fabric at temperature T_1 and of cross sectional area greater than A is placed on the copper disc and if there are n fiber contacts per unit area with the surface of the copper disc and each fiber has specific conductance k (units are cal/sec deg/cm length), then there exists a length, l, of these fibers over which the temperature drop $(T-T_1)$ occurs. If it be assumed that this length, l, corresponds to the height of the fuzz on the fabric then the rate of gain of heat by bulk fabric is

$$\frac{dH}{dt} = \frac{nkA}{l}(T-T_1) \qquad (2)$$

At any instant of time the amount of heat being lost by the penny equals that being gained by the fabric. Equating (1) and (2) gives

$$\frac{nkA}{l}(T-T_1) = -Mc\frac{dT}{dt} \qquad (3)$$

If the temperature difference $(T-T_1)$ corresponds to a linear galvanometer deflection, g, of the temperature measuring system, then

$$g = B(T-T_1) \qquad (4)$$

and $$\frac{dg}{dt} = B\frac{dT}{dt} \qquad (5)$$

Substituting equations (4) and (5) in (3) gives

$$\frac{nk\ Ag}{l} = -Mc\,\frac{dg}{dt} \qquad (6)$$

$$\text{or} \quad dt = \frac{-l\ Mc}{nkA}\,\frac{dg}{g} \qquad (7)$$

Integrating equation (7)

$$t = \frac{-2303\ lMc}{nk\ A}\ \log g + I \qquad (8)$$

where I is the constant of integration. If at time t = 0, g = 1 (full scale deflection) then I = 0 and

$$t = \frac{-2.303\ l\ Mc\ \log g}{nk\ A}\ . \qquad (9)$$

Where a plot of <u>t</u> vs. log g is linear with slope <u>m</u>, then

$$\frac{nk}{l} = \frac{-2.303\ Mc\ m}{A} \qquad (10)$$

The parameters descriptive of the fabric surface are grouped on the left-hand side of equation (10) while on the right are the apparatus constants and the experimentally determined slope <u>m</u>.

Up to this point in the analysis, the assumption has been made that all heat losses from the copper disc occur to the surface fibers of the fabric. In actual practice two other types of heat loss to the environment affect the rate of cooling of the hot penny: 1) losses to the insulation on which the copper disc is mounted and 2) losses to the air surrounding the fiber contacts and trapped between the disc and the fabric.

The heat loss to the insulation will appear as a correction to the slope <u>m</u> so that equation (10) may be written as

$$\frac{nk}{l} = C\,(m - m_o) \qquad (11)$$

(C is the apparatus constant = $\frac{-2.303\ Mc}{A}$).

The correction term, m_o, may be estimated from hot penny runs with smooth surfaced substances of known conductance. Experimental details for obtaining m_o have been given in Report No. 2.

If it is desired to determine the heat losses to the fabric surface independent of the air trapped at the fuzz, then losses to this air must be accounted for in the equations. If the effective fractional cross-sectional area of the fabric surface made up of air is $\bar{a}$ and the specific conductance of air is k_a, then equation (11) becomes

$$\frac{nk}{l} + \bar{a}k_a = C\,(m - m_o). \qquad (12)$$

Where m_a is the experimental slope of log g vs. t curves for losses to air only, the final hot penny equation is

$$\frac{nk}{l} = C\,(m - m_o - m_a) \qquad (13)$$

It has been shown in Report No. 2, that it is possible to use a value of $\bar{a}$ = 0.9 in the general case for real fabrics. For the particular apparatus constructed in these laboratories the "corrections" m_o and m_a were incorrectly given in Report No. 2; the values in proper units are m_o = 0.00100 sec^{-1} and m_a = 0.00132 sec^{-1}.

In actual use of the hot penny apparatus the linearity of the curves obtained by plotting log g vs. t (slope m) falls off as t becomes large. This means that heat losses from the fabric fuzz become appreciable as the fabric surface is heated to hot penny temperature. It has been observed however that the following empirical relationship holds;

$$\log G = -Rt + S, \qquad (14)$$

where $G = \log g$, $R = k' m$, k' is an apparatus constant and S is the value of $\log G$ when $t = 0$. Substituting in equation (14),

$$m = \frac{S - \log G}{k' t} \tag{15}$$

Values of m calculated in this manner are identical with those obtained graphically from the log g vs. t plots but permit the use of all of the data from a hot penny experiment. This method is particularly useful when m is large (the disc cools rapidly) in which case it may be difficult to estimate m graphically with any degree of precision.

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Table 1, Report 3, Drop Absorption Tests of Laundered Serges.

Code	Fiber Composition		Drop Absorption (0.2 ml.)
	Wool %	Other* %	Time seconds
		Group A	
745	100	0	> 18,000
741	70	30 O	130
742	70	30 Da	3,500
743	70	30 O	180
744	70	30 Da	13,000
746	70	30 V	40
747	70	20 V, 10 N	70
748	70	30 Ch	200
		Group B	
54047	70	30 Dy	540
54048	50	30 VC, 20 N	1,600
54049	50	30 A, 20 N	60
20	70	30 Dy	640
21	50	30 VC, 20 N	4,600
19	50	30 A, 20 N	100
		Group C	
Ny	0	100 N	15
28	0	100 C	2
		Group D	
A	100	0	> 17,000
13	100	0	> 25,000
H	100	0	160
K	100	0	2,400

* O = Orlon, Da = Dacron, V = Viscose, N = Nylon, Ch = Chemstrand,
VC = Vicara, Dy = Dynel, A = Acetate, C = Cotton.

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Table 2, Report 3. Wicking Times as a Function of Twist for Rovings of Various Fibers.

Fiber	Height of Rise of Water in.	Time for Water to Rise At: 1/2 tpi sec.	2-1/2 tpi sec.	5 tpi sec.	9 tpi se.
Nylon	1	19000	3300	90	150
Nylon	1.5	-	10000	200	-
Nylon	1.75	-	>26000	410	-
Wool	1	> 260000	6200	3500	-
Wool	1.5	-	35000	5800	-
Wool	1.75	-	-	7900	-
Wool, short staple	1	> 260000	3600	1400	-
Wool, short staple	1.5	-	5900	2900	-
Wool, short staple	1.75	-	> 10000	4000	-
Viscose	1	30	40	50	>29000
Viscose	1.5	80	70	160	-
Viscose	1.75	110	120	340	-
Viscose-HCHO treated	1	40	60	70	110
Viscose-HCHO treated	1.5	90	100	180	360
Viscose-HCHO treated	1.75	140	150	-	710

Table 3, Report 3. The Effect of Extraction on Wicking of All Wool Fabrics.

Material	Condition	Drop Absorption Time sec.
K	Unextracted	930
	Extracted	10,000
H	Unextracted	110
	Extracted	210

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Table 4, Report 3. Wicking of Napped and Sheared Fabrics.

Sample	Longitudinal Wicking sec./1 in. rise	Drop Absorption (0.2 ml.) Time sec.
28 - Cotton serge	16	2
" - napped	16	3
N - Nylon serge	35	10
" - napped	170	9300
A - Smooth Wool serge	>15000	8500
" - napped	-	>29000
742 - Blended serge (30% Dacron)	870	3500
" - napped	870	>29000
746 - Blended serge (30% Viscose)	75	30
" - sheared	60	14
" - napped	130	1500 to 18000
741 - Blended serge (30% Orlon)	-	120
" - napped	-	150
745 - Hairy wool serge	-	>14000
" - sheared	-	8200

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Table 5, Report 3. Thermal Resistance (1.0 lb/in^2) of Serges as Related to the Fabric Surface.

Sample	Thickness mils	Intrinsic Thermal Resistance °C sec m^2/cal	Specific Resistance °C sec m^2/cal in.
Cotton serge	36	0.048	1.34
" - light nap	37	.052	1.41
" - heavy nap	42	.064	1.53
Nylon serge	36	.050	1.39
" - light nap	40	.060	1.52
" - heavy nap	43	.071	1.65

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Table 6, Report 3. The Evaluation of Hairiness from Surface Photographs.

Height of Grid Line Above Base mils	Number of Intersections per 240 mils		
	Smooth Serge A	Serge A Napped	Hairy Wool Serge 13
6	45	99	68
12	17	67	31
18	7	35	20
24	5	21	12
30	2	12	4
36	0	5	2
42	0	2	2
48	0	2	1
56 or greater	0	4	3
Number of fibers 6 mils or longer in 240 mil section	45	99	68
Total length of fiber in 240 mil section	456	1482	858
Fraction of fibers 18 mils or longer	0.16	0.35	0.29

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Table 7, Report 3. The Effect of Napping and Shearing on the Fabric Surface as Shown by Hot Penny Measurements.

Sample	Time to Cool 7.5°C.($t_{1/2}$)		Calculated Ratios of Number of Surface Fibers to Length (n/l)	
	At self pressure sec.	At 0.1 lb/in^2 sec.	At self pressure cm^{-3}	At 0.1 lb/in^2 cm^{-3}
Hairy wool serge (13)	93	77.5	16 x 10^4	26 x 10^4
" - sheared	86	68.5	20	33
Smooth wool serge (A)	74	51	31	54
" - napped	93	65	15	34
Blanket (HB)	111	108	4.4	5.6
" - sheared	95	90.5	7.0	9.5
Nylon serge	70.5	41	53	106
" - napped	77.5	45.5	37	90
Rayon twill - filament	61.5	31	94	200
" - staple	78	37	50.5	165

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Table 8, Report 3. Hot Penny Measurements at Various Pressures.

Sample	Added Weight gms.	Pressure lb/in^2	$t_{1/2}$ sec.	Calculated n/l cm^{-3}
13 - Hairy wool serge	5	0.088	77.5	44×10^4
	2	.037	76.5	38
	1	.020	84	36
	0	.0028	93	27
A - Smooth wool serge	5	.087	63.5	64
	2	.036	71	45
	1	.019	82.5	42
	0	.0023	90.5	30
N - Nylon serge	5	.087	50.5	82
	2	.036	59	64
	1	.019	64.5	59
	0	.0018	81.5	37
28 - Cotton serge	5	.088	47	100
	2	.036	52	91
	1	.019	56	80
	0	.0024	76	46

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Table 9, Report 3. The Surface Character of Laundered Fabrics as Evaluated by the Constant $b = (p + 0.05)(t-a)$.

Code	Fabric Description	Equation Constants* a mils	Equation Constants* b lb/in
13	Hairy wool serge	42	3.47×10^3
A	Smooth wool serge	34	1.94
28	Cotton serge	33	1.85
N1	Nylon serge	35	1.21
54047	Blended wool serge (30 Dynel)	28	1.59
20	" - napped one side	28	2.47
54048	Blended wool serge (30 Vicara, 20 Nylon)	28	2.33
21	" - napped one side	29	2.99
54049	Blended wool serge (30 Acetate, 20 Nylon)	29	1.70
19	" - napped one side	29	2.74
RL-f	Filament rayon twill	16	0.23
RL-s	Crimped staple rayon twill	16	0.71
RS	Rubber sheeting	34	0.21

*Calculated from the loading cycle only and in the case of b for pressure values to 0.1 lb/in^2.

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Table 10, Report 3. Correlation of Subjective Handle of Tropicals with b Value Calculated from Compression Data.

Sample	Subjective Handle, Smooth to Fuzzy	Value of b from Compression Data lb/in
A	1	0.57×10^3
D	2	.51
C	3	.69
H	4	.56
E	5	.73
F	6	.74
B	7	.90

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Table 11, Report 3. The Effect of Shearing or Napping on the Surface Character of Fabrics.

Sample	Additional Finishing Process	Thickness (t) at .002 lb/in^2 mils	b* lb/in.
Nylon serge (pressed)-N2	None	40	0.49 x 10^3
Nylon serge (pressed)-N2	Napped	71	1.58
Blanket-NB	None	296	11.9
Blanket-NB	Sheared	238	8.7
Hairy wool serge-13	None	115	3.47
Hairy wool serge-13	Sheared	79	2.25
Smooth wool serge (pressed)-A	None	47	0.90
Smooth wool serge (pressed)-A	Napped	86	2.69
Blended serge - 54047	None	64	1.59
Blended serge - 20	Napped	80	2.47

*From loading cycle in the pressure range 0.002 to 0.1 lb/in^2

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Table 12, Report 3. Results of Tests of Dry Cleaned Tropical Fabrics.

Test	Sample Code						
	A	B	C	D	E	F	H
Approx. Fiber Composition, %							
Wool	-	100	20	90	100	-	100
Mohair	-	-	-	-	-	40	-
Viscose	50	-	80	-	-	40	-
Nylon	-	-	-	10	-	5	-
Acetate	50	-	-	-	-	15	-
Weight per sq. yd., oz.	6.8	7.2	5.8	5.4	6.0	7.0	6.8
Thickness, mils							
At 0.002 lb/in^2	28	38	29	25	31	33	29
At 1.0 lb/in^2	18	22	16	17	19	19	19
Thermal Resistance at 0.002 lb/in^2, °C m^2 sec/cal.	0.070	.094	.074	.063	.076	.075	.072
Air Permeability, ft^3/ft^2/min.	71	31	140	77	62	73	29
Mean Bending Length, cm.	1.65	1.8	1.7	1.75	1.75	1.85	1.75
Mean Crease Recovery, Dry, %	73	84	71	88	86	76	84
Crease Recovery, Wet, %							
Warp	40	54	30	50	53	37	55
Filling	28	51	31	51	48	62	54
Muss Resistance, Rank	1	3	4	3	3	2	3
Perspiration Fastness Class	5	5	5	5	5	5	5
Area Felting in Laundering, %	3	5	4	4	5	4	5
Handle, Rank							
Soft to Harsh	5	3	4	1	7	6	2
Smooth to Fuzzy	1	7	3	2	5	6	4
Mean Flexural Rigidity, g. cm.	0.10	.16	.10	.10	.11	.15	.12

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Table 13, Report 3. Ranking of Characteristics of Tropical Fabrics.

Test	Sample Code							No. of Classes
	A	B	C	D	E	F	H	
Weight	3	3	2	1	2	3	3	3
Thickness	2	4	2	1	3	3	2	4
Thermal Resistance	2	3	2	1	2	2	2	3
Air Permeability	2	3	1	2	2	2	3	3
Sums of Ranks	9	13	7	5	9	10	10	13
Crease Recovery, Dry	3	1	3	1	1	2	1	3
Crease Recovery, Moist, W	2	1	3	1	1	2	1	3
F	3	2	3	2	2	1	2	3
Muss Resistance	1	3	4	3	3	2	3	4
Sums of Ranks	9	7	13	7	7	7	7	13
Handle								
Soft to Harsh	5	3	4	1	7	6	2	7
Smooth to Fuzzy	1	7	3	2	5	6	4	7
Flexural Rigidity	2	1	2	2	2	1	2	2
Sum of Ranks.	8	11	9	5	14	13	8	16

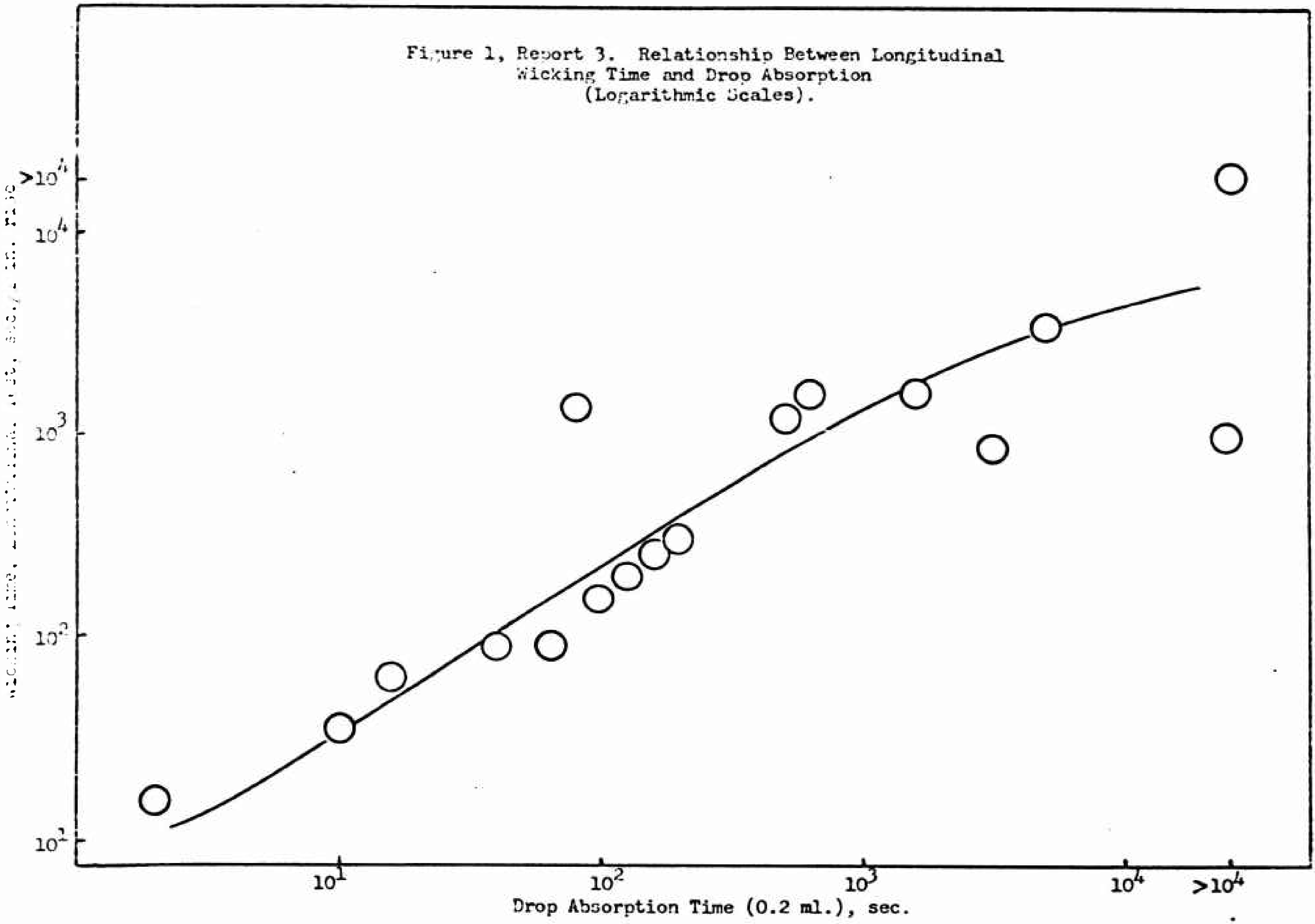

Figure 1, Report 3. Relationship Between Longitudinal Wicking Time and Drop Absorption (Logarithmic Scales).

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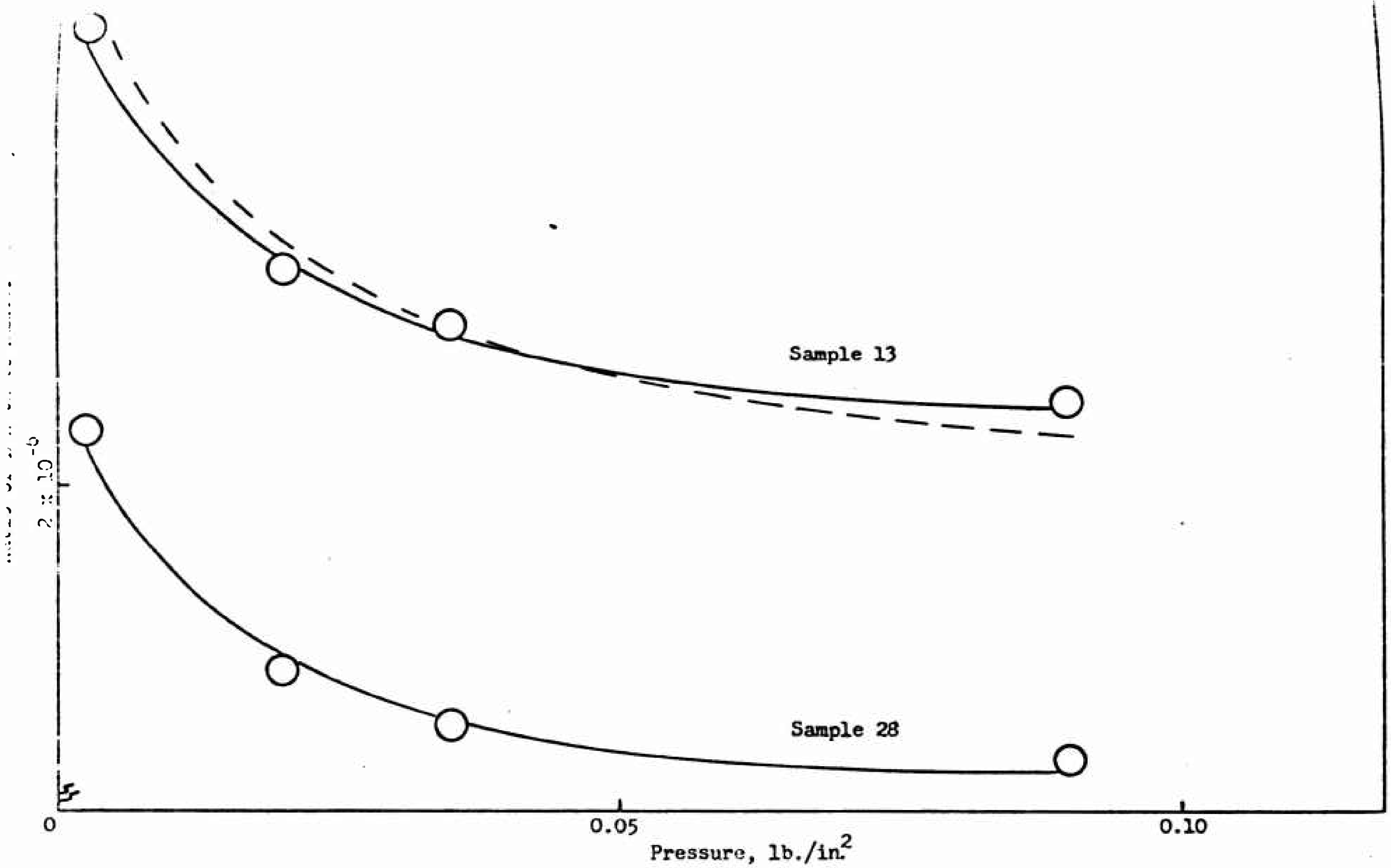
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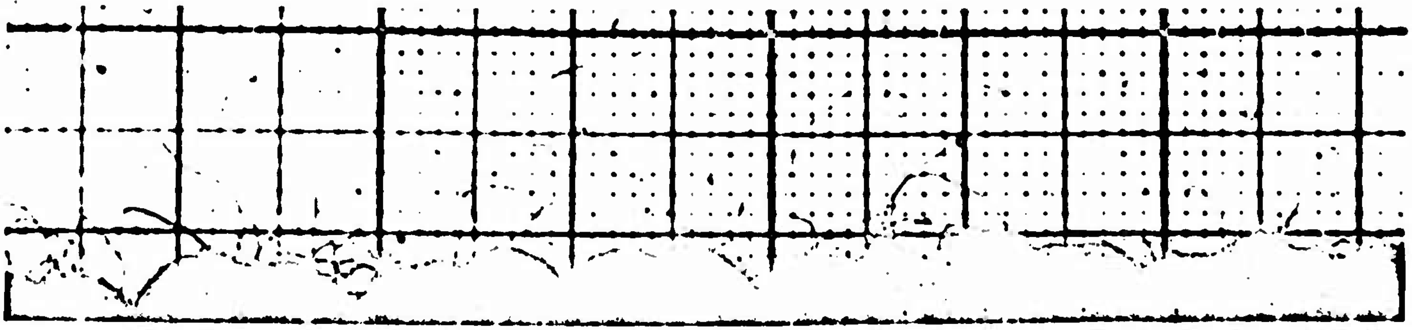
Sample 13
Sample 28
0
0.05
0.10
Pressure, lb./in.²



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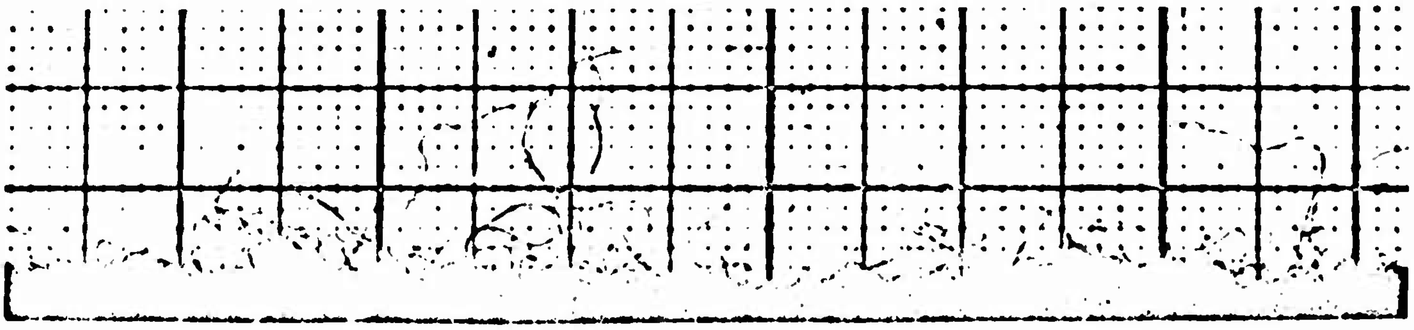

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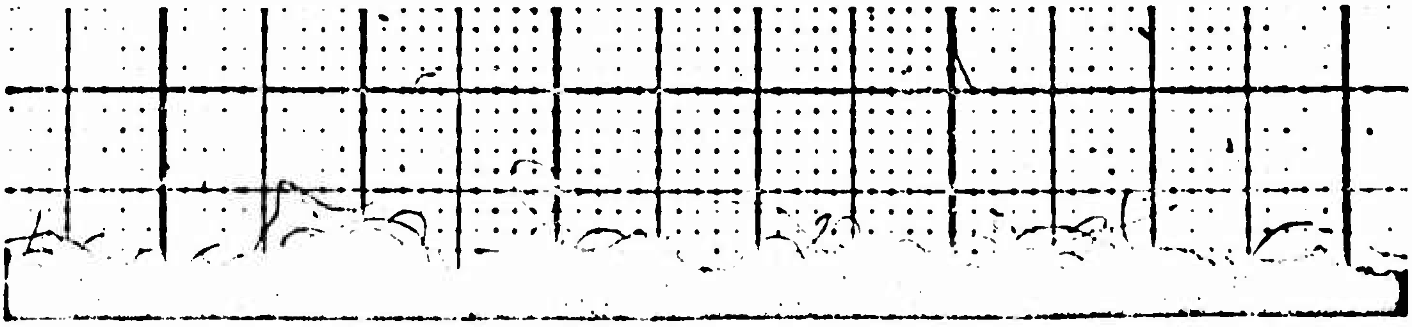

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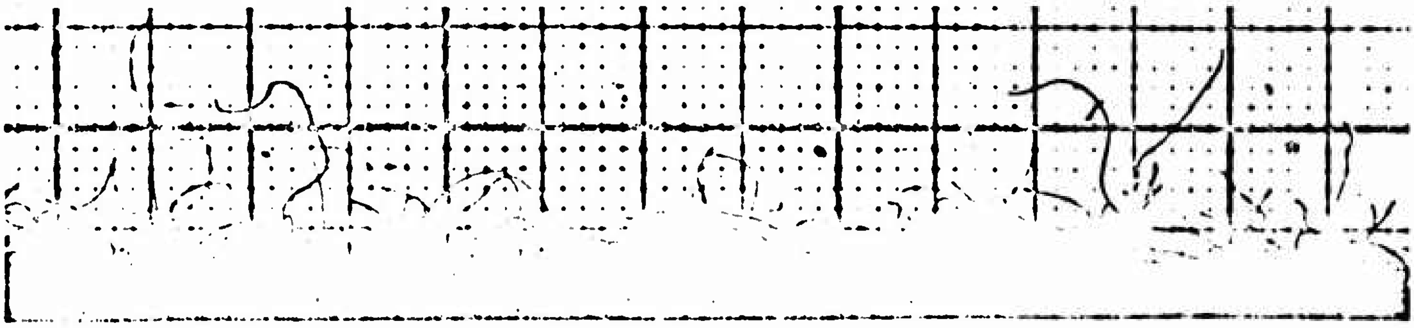

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