

AN EVALUATION OF FACTORS AFFECTING THE FRICTIONAL PROPERTIES
OF A SELECTED COTTON FIBER SAMPLE

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Thomas Robert Boys

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SUMMARY

A limited amount of research has been directed toward the subject of cotton fiber friction, though this frictional force between fibers is considered to be partially responsible for the strength of cotton yarns and fabrics. In the past few decades, however, there has been an increased interest in this fiber characteristic and the several factors which contribute to the total frictional force. A study of fiber friction should begin with the isolation and complete evaluation of each of these contributing factors for a known and typical sample. For a study of cotton fiber friction these factors are shape, surface, and structure; and a typical or standard sample is a cotton which represents, to as high degree as possible, all varieties of fiber grown and/or used in a particular area.

In this investigation, Empire WR cotton was selected as a typical southeastern variety and the fiber shape factor, consisting of convolutions and crimps along the fiber, was evaluated relative to cotton fiber friction.

The Empire WR variety of cotton was selected as a standard for the investigation because this is a variety grown extensively in the southeastern United States and used by many mills throughout the nation. Empire WR was developed by the Georgia Agricultural Experiment Station at Experiment, Georgia, and in 1963 was among the ten leading varieties planted, on an acreage basis, in the United States. Fiber from the 1962 crop was used as an experimental sample while a standard sample was be-

ing grown during 1964. The growth of this latter, or standard, sample was controlled to insure the production of a cotton which is typical of southeastern cottons.

Convolutions and crimps in the experimental (1962) fiber were observed with optical microscopes; the results of the observations indicated that there is a significant difference in the number of convolutions and crimps per inch of fiber for several of the fiber lengths observed. Convolutions per inch were found in the range 65.4 to 91.5; crimps per inch in the range 14.7 to 19.4.

After the standard (1964) fiber sample had been picked and ginned, a comparison was made between this cotton and the experimental fiber. It was found that these fibers have almost identical weights per unit length and staple lengths, and can be assumed to be physically similar. For this reason, it was assumed that the data which describe the experimental fiber also describe the standard cotton and may be of value in a study of cotton fiber friction force, providing such a study utilizes the submitted standard cotton as a basis.

CHAPTER I

INTRODUCTION

During the last two or three decades textile structures have found increased utilization in load-supporting applications. As a result, there is today much interest in the mechanical properties of fibers, yarns, and fabrics. Pierce, Hamburger, and others have contributed generously to the available information on the mechanical properties of various textile structures. However, in many of these investigations, the effect of friction has been assumed slight or completely non-contributory. Many textile engineers and textile research men today feel that this has been an incorrect assumption and that friction in textiles should receive further investigation.

The topic of friction related to textile structures may logically be classified under such categories as fiber friction, yarn friction, and fabric friction. This present investigation is concerned with factors of cotton fiber friction only.

Frictional characteristics of fibers are the most basic of textile friction considerations, and possibly the most complex. These characteristics are of extreme interest when the mechanical processes involved in textile manufacture are considered.

When fiber friction is defined as fiber to fiber clinging power, a power consisting of surface friction and shape interlock, some of the factors which contribute to the frictional properties of a fiber are shape, structure, and surface properties. The influence of each of these

relative to one another is still unresolved; but the influence of shape factors would seem perhaps to be greater than that of the other two. Important shape factors with which we are concerned are convolutions, crimp, cross section, and staple length.

The study of these frictional factors must necessarily begin with experimental investigations of each factor separately. Each of these experiments is intended to produce data describing as fully as possible a particular factor, and that factor only, in a specific and reliable manner.

The selection of a sample to be used in a fiber friction study is of major importance; as the results of the investigation may significantly depend upon this selection. In order that the experimental results not be unduly limited by sample or specimen choice, the measurements were made with regard to a typical or "standard" fiber of known specifications. The techniques utilized in this study were therefore applied to a specially selected cotton fiber as it came from the gin.

This study was planned to include the development of experimental techniques for the evaluation of frictional factors using a selected sample and a pains-taking selection of a standard sample of similar quality for comprehensive additional research. The necessity for similarity of these two samples is of considerable importance because these later friction studies will be based, to a large extent, upon them. A complete description of both the experimental and "standard" fiber samples is presented later, but it should be borne in mind that these samples are of the same variety and were grown in the same area.

The importance of the selection of a "standard" sample can hardly

be over-emphasized. In all experimental investigations reference must first be made to the characteristics of a known specimen; experimental conditions; and/or equipment. Without such reference the results of a particular study are, to a considerable degree, insignificant. However, when reference can be made to a standard, definite conclusions can be drawn and special cases and comparisons represented.

Before discussing selection of samples further, let us consider some of the characteristics of a cotton fiber which govern its frictional properties.

The mature cotton fiber consists of a flat filament with convolutions occurring along its length. These convolutions seem to contribute rather extensively to the fiber to fiber bonding characteristics of cotton fibers. It has been discovered that these convolutions vary considerably from fiber to fiber.

The presence of crimps along the length of the cotton fiber is also an important consideration in relation to fiber friction. The variation of these crimps per unit length of fiber has apparently not been extensively investigated.

Elastic properties must certainly be considered when fiber shape is being investigated. This is the property which determines the fiber shape retention. Because of its complexity and the time element involved, elastic properties of cotton fibers were not closely examined; but this factor was not overlooked.

The length of a particular fiber also contributes to the structure of yarns made from it. Therefore, facts about convolutions vs. staple length, crimp vs. staple length, and the degree of variation of

each of these factors within the sample should be established.

In view of the preceding considerations, this study will investigate the statistical occurrence of cotton fiber convolutions and crimp and the relationship of these factors to the staple length. In order to give the investigation higher validity, the tests were applied to a cotton sample of known history, variety, and physical characteristics. The Empire WR variety of cotton fiber was selected as a typical southeastern cotton. This fiber was grown by the Georgia Experiment Station of the United States Department of Agriculture's Agricultural Research Service at Experiment, Georgia. A portion of this experimental sample of 1962 cotton was then separated according to staple length and used for the experimental phase of the study.

While the properties of the experimental sample were being investigated, approximately 1.5 acres of Empire WR were being grown for use in further friction studies. The growing, hand picking, ginning, and blending of this 1964 crop were carefully observed and controlled in order that this fiber might be similar to the 1962 fiber. The similarities of these cottons were evaluated and a bale of the 1964 fiber was stored at the A. French Textile School at Atlanta, Georgia, for future studies of fiber friction.

Literature Survey

The study of friction between solids was first reported in the work of da Vinci¹, Amontons², Coulomb³, and Morin⁴. From the investigations of these four scientists came the generally accepted "old laws" of frictional phenomena. These laws, as expressed by Copeland and Scheibner⁵

are: (1) the frictional force is proportional to the normal load, that is, $F = \mu N$; (2) the frictional force is independent of the area of contact; (3) the force of friction is independent of velocity, and $\mu_s > \mu_k > \mu_r$, where s, k, and r represent static, kinetic, and rolling, respectively; and (4) the frictional force depends upon the nature of the contact surfaces. These laws have been used in most textbooks although there is no experimental proof of the third law, and the relationships involving relative smoothness are frequently vague when stated in conjunction with the fourth law.

Coulomb felt that the frictional force was caused by the cohesion of surfaces in contact and by the interlocking of surface asperities. But this meant that the frictional force would be proportional to the apparent area of contact. Unfortunately, Coulomb abandoned the cohesion theory when experiments failed to yield conclusive evidence of the validity of the theory. Bowden⁶ and his associates, however, have devised an experiment which has shown that the cohesion theory may be correct.

When the topic friction is restricted to fiber friction, much confusion usually exists. This confusion exists because of a need for a clear definition of fiber friction under various conditions. As stated by Sangston and Rainey⁷, measurement of fiber friction is by no means a standardized procedure and no perfectly satisfactory measuring technique has been developed. This statement seems to apply especially to cotton as no method has been developed which will allow the calculation of the coefficient of friction of a particular cotton fiber. The equation describing the relationship between the coefficient of friction and the normal load for a monofilament yarn has, however, been developed by

Whitney⁸. This equation was derived from mathematical expressions involving the area of contact and was checked by measuring friction as a function of tension when the monofilament yarn was passed over a cylindrical surface.

This equation is

$$\mu = \frac{f}{n} = a + \frac{b}{n^{1-c}} \quad 0 \leq c < 1$$

where f is the frictional force per unit length; n is the normal force per unit length; a is a mechanical constant related to the area of contact; b is a deformation constant ($2/3 \leq b < 1$); and c is a constant which takes plowing, cohesion, static electricity, etc. into consideration ($0 \leq c < 1$). When this equation is rearranged we get

$$f = an + bn^c.$$

As previously stated, the experiments by Whitney proved this friction equation. However, it will be noted that if $c = 0$, we have a linear form of the equation and if the deformation constant, b , is equal to zero, the equation is reduced to the widely used friction equation.

Whitney also states that, "...friction force is almost totally dependent on area of contact and is dependent on load only as it affects the area of contact."

This statement means that the frictional force is proportional to the area of contact; therefore the same type of relationship exists

for area of contact vs. frictional force and normal load vs. frictional force.

A very interesting research experiment has been reported by Adderley⁹ in "The Clinging Power of Single Cotton Hairs". The clinging power of the single fiber was found to be analogous to the coefficient of friction. Adderley's study was particularly directed toward the presence of convolutions along the cotton fiber and the effect of these configurations upon the clinging power of the fibers.

The investigation began with the assumption that the engaging of the convolutions of adjoining fibers is responsible for a significant portion of the clinging power. The assumption was tested by placing a single fiber between pads covered with cotton fibers of the same type and then measuring the force required to withdraw the single fiber from between the pads. The fibers mounted on the pads and the single fiber were parallel to as great a degree as possible. After this force of withdrawal was measured it was related to the previously determined convolutions per centimeter in that particular fiber. A graph was prepared showing the relationship between the force required to withdraw the fiber and the convolutions per centimeter.

The graph displays a curve with a well defined maximum, Figure 1. This maximum, in Adderley's words, indicates that:

When the hair placed between the pads has the same convolutions as the coverage hair of the pads, the chances are that it will be against a hair with which its convolutions will engage more or less perfectly. If the hair placed between the pads has not the same average convolutions as the hairs of the pads, the chances that it will be against a hair with which it engages perfectly will be fewer and the average force necessary to cause it to slip will be less.

The fact that this force does not remain constant for various numbers of

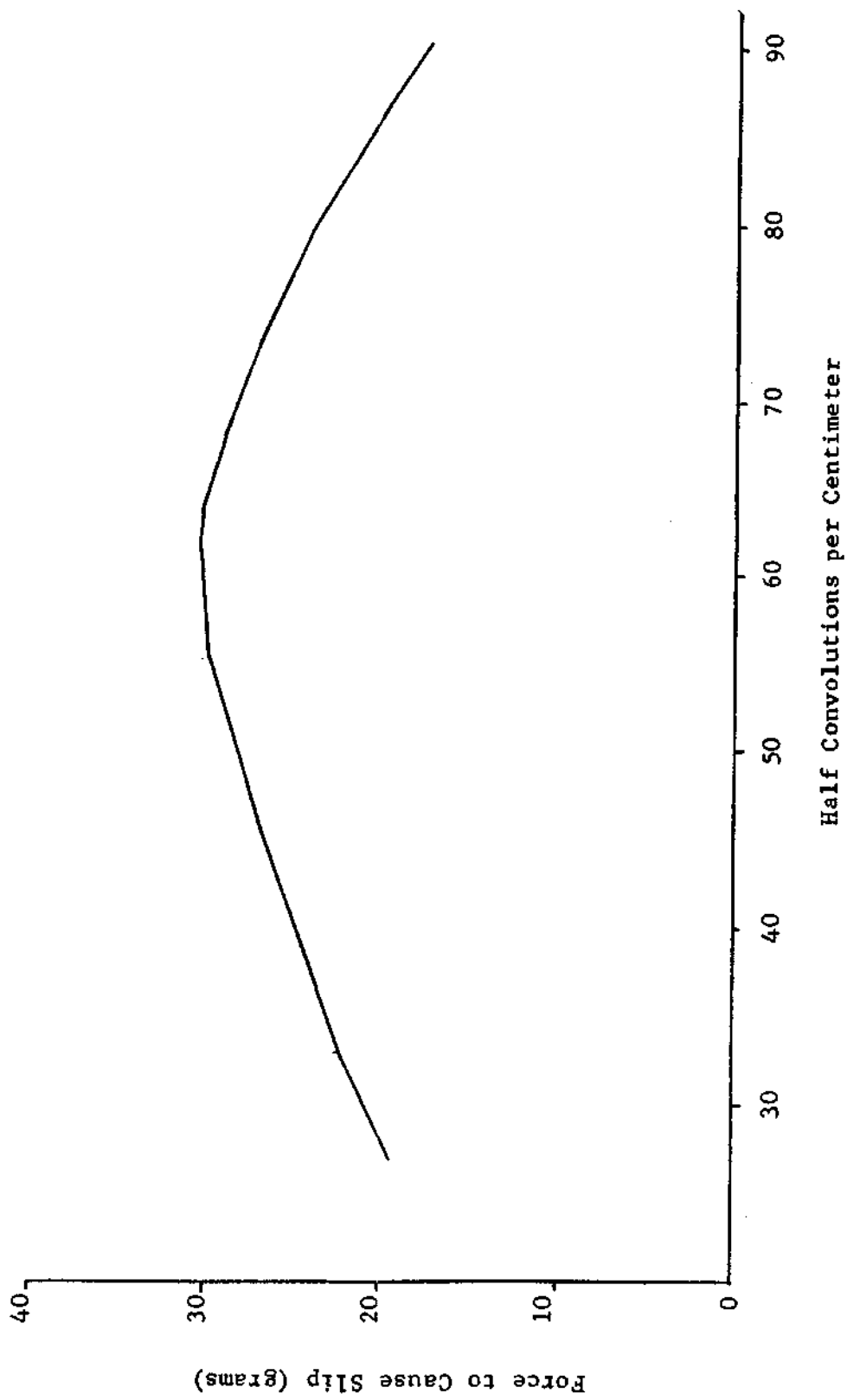


Figure 1. Clinging Power of Sea Island Cotton

Source: Adderley

of convolutions per centimeter in this relationship indicates that convolutions have a definite effect upon clinging power; and the presence of a single maximum point on the curve indicates, as far as spinning considerations are concerned, a very desirable mechanical condition.

While this study has not concerned itself with a determination of convolutions per unit length, this author feels that this factor is of more than passing interest. For this reason a paper by Betrabet, Pillai, and Iyengar¹⁰ concerning the convolution angle and convolution per unit length of cotton fibers is worthy of mention here. The purpose of their investigation was to establish a relationship between Pressley index and convolution angle for certain Indian cottons. The study showed, with some reservations, that fiber strength decreases with increasing convolution angle. A method for determining the number of convolutions per unit length was also developed.

To determine the number of convolutions per unit length, a small tuft of fibers was pulled from a representative sliver and mounted straight and parallel on a slide. The lengths and numbers of convolutions were determined microscopically....

Determinations of convolutions per unit length were made over the full length of the fiber and over the central 5mm. region only. The correlation coefficient between the two values on 10 cottons was 0.927, so further determinations were made on the central region only.

This test shows that, at least for these ten cottons, convolutions per unit length is a reasonably constant value along the length of a particular cotton fiber.

Crimp has been thought to be a very important characteristic of fibers for many years but little research has been directed toward crimp in natural fibers. Several studies have been made concerning wool, in-

cluding one by Snyman¹¹; but there is a lack of information on the relationship between crimp and spinnability, staple length, maturity, and other properties of cotton, wool, and other natural fibers.

The snyman report discusses a method for determining the number of crimps per inch in wool fibers. This method utilizes a linen prover with a magnification of only four and one-half times and therefore is not suitable for determining the amount of crimp in cotton fibers.

The Suter-Web sorter was used to separate the various lengths of cotton fiber for the microscopic determinations of convolutions and crimp in this investigation. Following the results of a test by Landstreet¹², each fiber was checked to insure that it was of the proper length before being subjected to microscopic examination. This was necessary because the Landstreet study showed that in each staple length group there were fibers with lengths outside the group limits.

A reproducible, quick, and simple method for examining the surface characteristics of natural and synthetic fibers has been developed by Goodwin¹³. The method involves a chemically deposited layer of metallic silver which enhances the surface detail of the fiber in order that the fiber may be examined with an optical microscope.

Fibers are taped parallel on a microscope slide between two pieces of double-backed transparent tape. A drop of 3% aqueous silver nitrate solution containing enough ammonium hydroxide to clear up the dark turbidity is placed on the fibers in the area between the tape strips. During this process, the fibers embedded in the tape will also become wet with the solution. A drop of 36% formaldehyde is added to the slide. The reaction, which is known as Tollen's test for an aldehyde, deposits a silver mirror on the filaments. The preparation is allowed to set from one to two minutes after which the excess liquid is blotted away and the fibers covered with a cover glass. The filaments are then studied directly under phase-contrast or bright-field conditions.

CHAPTER II

THE CHARACTERIZATION OF THE STANDARD

Selection of the Experimental Sample

The fiber selected for this study and assumed to be a typical southeastern cotton was of the Empire WR variety. This variety is an early-opening, wilt-resistant, medium-staple cotton grown extensively in the Piedmont and Delta regions of the Southeast and is quite popular in southern mills. In 1963 Empire WR was among the ten leading varieties planted in the United States, accounting for 17 percent of the total cotton acreage in Alabama, 16 percent in Georgia, 8 percent in Florida, 16 percent in Tennessee, and 1 percent in each of the Carolinas, Mississippi, and Arkansas.

Empire WR was developed by the University of Georgia Agricultural Experiment Station at Experiment, Georgia, and is grown each year by the station. Typical variety test results are those of the 1963 crop, Table 1.

The fiber which was utilized as the experimental sample was grown during 1962 at Experiment. This particular fiber was machine picked, ginned at Harrelson, Georgia, and stored in a bale at Experiment. The cotton was removed from the bale in May, 1964, fluffed, and stored under standard textile laboratory conditions (70° Fahrenheit, 68% relative humidity) at the A. French Textile School on the Georgia Institute of Technology campus. The cotton was allowed to condition for one week and was then tested on Sheffield's Micronaire and Spinlab's Digital Fibrograph. Micronaire results averaged 4.02 micrograms per inch of fiber. This

weight is typical of southeastern cottons. The average result of the Fibrograph test was a 2.5 percent span length of 1.043 inches. This staple length is average for most southeastern cottons. By definition, the 2.5 percent span length is equivalent to the classer's length.

The overall appraisal of Empire WR as a typical or standard sample for fiber friction experiments is that this cotton meets all criteria quite satisfactorily. While several other cotton varieties such as Coker, Dixie King, and Deltapine could probably have been used as a standard, Empire WR seems to be more typical of all cottons grown in the Southeast.

Optical Equipment

The convoluted configuration of the sample was examined microscopically. An E. Leitz binocular microscope was used for the study which consisted of counting the number of convolutions per individual fiber. A ten power eyepiece, a one and six-tenths power binocular column and an eleven power objective lens were installed on this microscope, yielding a total magnification of 176. An E. Leitz Ultropak system was utilized for the study. The Ultropak is a microscope system which directs light through a condenser surrounding the objective lens and onto the specimen. The light is reflected from the specimen, through the objective, the eyepiece, and into the eye.

It was found that the cotton fibers had to be examined three dimensionally in order to properly evaluate the crimped characteristic of each fiber. For this reason, and because a low magnification was desired, a Bausch and Lomb stereoscopic microscope was used to examine these crimps. The microscope was equipped with 15 power eyepieces and 0.66 power objectives which yielded a total magnification of 9.90. The light source used

for this examination was a standard illuminator manufactured by American Optical Company. This light from the source was directed onto the specimen and not transmitted through the fiber being examined.

Experimental Techniques

The fiber sample from the 1962 cotton crop was initially prepared for microscopic examination by separating the various fiber lengths with a Suter Web Sorter. This operation was intended only to separate the fibers into long, average, and short length groups. A more exact measurement of the length of each fiber was achieved by carefully placing the fiber on a piece of black velvet fabric which was glued to a stiff backing. The fiber to be measured was very gently pulled out to its full length with a pair of tweezers and then measured with a standard six inch scale. The smallest division on this scale was one-sixteenth of an inch, so the cotton hairs were measured to within one thirty-second of one inch over or under the desired length. Fibers whose lengths were outside this one-sixteenth inch range were discarded.

At a magnification of 176 times the depth of focus of an optical microscope is quite short, so it was necessary that the fiber specimen be pressed flat under the objective lens. This gentle flattening of the fiber was accomplished by mounting the specimen dry between two plain microscope slides. Care was taken in this step to avoid applying excessive pressure to the fiber trapped between the slides. High pressure upon the specimen at this point could cause a compressive rupture of the fiber which might alter the number of convolutions or convolution direction reversals in a particular fiber.

Very immature (thin-walled, round) fibers were not used in the

study. These thin-walled fibers have a very low number of convolutions along their length due to the incomplete collapse of the wall of the fiber. It is the collapse of this lumen which causes the fibrilles to assume helix configuration and which, in turn, results in the convoluted fiber shape. Had these very immature or round fibers been evaluated and recorded, the data would have had a range which would have caused the results to be statistically erroneous. Broken fibers, that is, fibers broken at both ends, were also discarded. Such fibers were longer until broken while being picked or ginned and did not represent a true convolution pattern in their shortened length.

The Empire WR cotton which was used for the evaluation of fiber crimp was measured in the same manner as that fiber which was utilized for the convolution study; that is, the staple length was limited to a one-sixteenth inch variability for a given fiber length.

Crimp in the cotton fiber is three dimensional and, therefore, cannot be microscopically examined by standard fiber evaluation methods. It was thought that this factor could be studied by suspending the single cotton fiber and examining it from two or more vantage points. This method, however, proved impractical, due to the very light weight of the fiber and the problem of isolating the specimen from air currents. The experimental technique which was found to give the clearest picture of the crimp configuration involved placing the measured fiber on a standard microscope slide which was covered by cellophane tape with adhesive on both sides and then examining the fiber through a stereoscopic microscope. The individual fibers were handled very gently with tweezers and were set upon the tape so that contact was established only at points on

the fiber which first touched the tape as the fiber was lowered to the adhesive surface. To avoid deformation of the crimp configuration, care was taken not to apply excessive force to the fiber in order to achieve a stronger bond between tape and fiber.

The crimp in cotton fibers is a non-uniform crimp, but appeared to this observer to be composed of undulations, or waves, of three fairly distinct lengths and, in addition to these fairly smooth waves, a kinked configuration of very short length. In order that these crimps could be consistently defined, observed, and counted; these kinks, or very sharp bends in the fiber were excluded from the study. The other undulations, having one-half wave lengths of approximately one, two, or three thirty-seconds of an inch, were easily observed at a low power of magnification and were the object of the crimp examination.

A very high range of values was exhibited in the convolution data. Consequently, a sample size of 25 for each staple length was necessary to yield statistically sound results. The crimp study, however, yielded fairly consistent data and a sample size of ten for each staple length was sufficient to cause the results to be statistically significant.

Discussion of Results

The experimental portion of this study was designed to yield data and techniques which would isolate and describe the shape factors in cotton fibers which affect fiber friction. These data yielded results which should be further considered when a more complete study of cotton fiber friction is undertaken.

Convolution Results

Fibers of seven different staple lengths, from one-half inch to

one and one-fourth inches in one-eighth inch increments, were observed under the microscope. After 25 fibers of each of the seven lengths had been examined by counting their convolutions, a mean number of convolutions for each fiber length was computed. The seven means were then converted by dividing each by its respective staple length. These converted means have units of convolutions per inch of fiber and are plotted as a function of fiber length in Figure 2.

As may be seen in Figure 2, fiber lengths of one-half, five-eighths, and one and one-fourth inches, displayed values of 65.4, 71.9, and 67.9 convolutions per inch, respectively, whereas fiber lengths of three-fourths to one and one-eighth inches exhibited fairly consistent convolutions per inch of 91.5, 84.8, 83.6, and 83.9.

Before accurate statements can be made concerning a relationship of this type, the validity of such a relationship must be established. For this case, confidence intervals and tolerance limits were calculated and are expressed on Figures 6 and 7, respectively.

The confidence interval for each fiber length was calculated as shown in Table 7 and represents the interval which will contain the true mean 95 percent of the time, i.e., there is a probability of 0.95 that the mean number of convolutions per inch of all 1962 Empire WR fibers of a given length will fall between the limits of the interval. Figure 6 shows that the shape of the curve from Figure 2 is reasonably maintained for this 95 percent level. This test indicated that there exists a typical number of convolutions per unit length for a fiber according to its total length and that this number is different for the different staple lengths.

Tolerance limits prescribe an interval which contains a specified percentage of all values of a given variable with a stated probability. For the convolution case, these limits were set to include 90 percent of all values of convolutions per inch with a probability of 0.95. These limits are shown in Figure 7 and it can be seen that the lowest values possible for this percentage of fibers are to be found in the shortest and longest fibers observed.

These statistical tests show that the relationship between number of convolutions per inch and fiber length is represented with a high degree of accuracy by Figure 2.

Figure 3 is a plot of total number of convolutions as a function of fiber length. This graph displays the variance from a linear relationship for one-half, five-eighths, and one one-fourth inch fiber lengths and the almost linear case for lengths of three-fourths, seven-eighths, one, and one and one-eighth inches. This figure is a conversion of Figure 2 and is intended only to further illustrate the significant difference in the convolution configuration for these cotton staple lengths.

According to Adderley⁹, the convoluted shape of cotton fibers has a significant effect on fiber-to-fiber clinging power, a power directly related to fiber friction. Adderley also states that a fiber with a number of convolutions near to the average number of convolutions for all fibers of a particular variety has the greatest clinging power because there is a good probability that this fiber will be in contact with a similar average fiber and the convolutions of the two fibers will be engaged. The data obtained by this investigation of Empire WR cotton seems to indicate that an average number of fiber convolutions might be

present in the staple lengths from three-fourths to one and one-eighth inches. If all assumptions are correct, it may be said that the convolution shape factor contributes to fiber friction to a greater degree for this range of fiber lengths than to lengths outside this range.

Crimp Results

Ten fibers of each of the seven staple lengths described for the convolution experiment were evaluated by counting the number of crimps in each fiber. An average number of crimps per fiber was calculated for each fiber length, and these means were transformed to units of crimps per inch as in the previous section. These average values of crimps per inch are expressed as a function of fiber length in Figure 4; and the mean values of crimps per fiber are expressed as a function of the same variable in Figure 5.

As for the convolution case, there is a significant variance in the number of crimps for the different fiber lengths. Reasonably consistent values of 16.8, 15.6, 16.5, 16.4, and 17.3 crimps per inch were found for lengths from five-eighths to one and one-eighth inches; while one-half inch fibers averaged 19.4 crimps per inch, and one and one-fourth inch fibers had 14.7 crimps per inch as a mean value.

The validity of this relationship was tested statistically as in the previous section and the results of these tests are shown in Figure 8 and Figure 9.

The confidence intervals calculated at the 5 percent level indicate a significant difference in the shortest and longest fiber lengths observed.

The tolerance limits expressed in Figure 9 show that when it is

assumed that 95 percent of all values of crimps per inch will be within the limits with a probability of 0.90, the highest values will be observed in one-half inch fibers and the lowest in fibers measuring one and one-fourth inches.

These tests indicate that the relationship expressed by Figure 4 is a valid one, and that there is certainly a significant difference in the number of crimps per inch for the one-half and one and one-fourth inch fibers.

Figure 5 is intended to emphasize the departure of the mean values of crimps per inch from the linear case.

A basic assumption in cotton fiber friction theory is that the shape factors, especially convolutions and crimp, have an important effect on overall fiber-to-fiber holding power. If this assumption is valid, there is a significant difference in the fiber-to-fiber holding power between the various staple lengths of Empire WR cotton.

It must be remembered that fiber crimp retention is dependent upon elasticity and rigidity in the fiber. These two characteristics can cause the affect of the crimp factor on fiber friction to be of greater or of lesser significance. Consequently, they must not be overlooked as factors of importance to further study.

It is shown in Chapter III that 50 percent of the 1962 Empire WR experimental sample are 0.489 inches in length, or longer. This means that more than one-half of the experimental cotton sample is composed of fibers which are shorter than one-half inch. It may appear that the study of convolutions and crimps should have included these very short fibers. These fibers were not observed, however, because these are the

fibers which are removed, in part, by the yarn manufacturing processes and the ultimate objective of this and other investigations relating to fiber friction is the translation of the results from such studies from the single fiber case to the more complex yarn and/or fabric configuration.

CHAPTER III

THE SELECTION AND PREPARATION OF THE STANDARD SAMPLE

History of the Sample

The Empire WR cotton which was selected as a standard for cotton fiber friction studies was grown near Experiment, Georgia, during the 1964 growing season. The period between April and November, the normal cotton growing season, was characterized by temperatures which are normal for this area of Georgia, and by rainfall which was considered slightly above average, especially near the end of the growing season. Although heavy rains fell during early October, beginning a few days after the bolls began to open, this moisture did not appear to affect the grade of the sample.

The standard sample was grown in a field approximately two miles west of the agriculture station in Experiment. The soil in this field is of the Cecil soil series, and may be further classified as a sandy clay loam.

Cecil series soils are derived from a granite gneiss. This gneiss or laminated rock causes these soils to be similar in mineral content to their granite origin. These soils, relative to other Piedmont soils, are quite fertile; but must be managed properly for good quality yields. Proper soil dressing, fertilization, and cultivation are absolute necessities for this soil series.

The most agriculturally important soils in the United States are the many types of loams. Ideal loams are soils which are a mixture of

sand, silt, and clay particles which exhibit light and heavy properties in about equal proportions. These loams generally possess the desirable qualities of both sand and clay without exhibiting the undesirable properties of extreme looseness and low water capacity of stickiness, compactness, and slow air and water movement. Loams are classified according to their major constituent(s); therefore, the soil in the area of Experiment, Georgia, is comprised chiefly of sand and clay particles and contains silt particles in a smaller percentage.

The particular field where the standard sample was grown has a sandstone underlie. It might be assumed that a Cecil soil, formed from granite, would be bedded on granite, but this assumption is not true in this case.

The field is also underlaid by a hardpan, or plowpan, at a depth of six inches. At the time of the picking of the standard, the field had not been subsoiled.

The field in which the sample was grown was prepared by plowing, followed by a broadcast fertilization with 700 pounds per acre of 4-12-12 fertilizer, and finally by a top dressing of ammonium nitrate applied at the weight of 250 pounds per acre. The cotton seed was planted during the last week in April, 1964, at a density of 20 pounds per acre. The field was cultivated a total of four times, once following the top dressing, and hoed to keep weeds away from the cotton plants. Flowers first appeared on the plants on August 4, 1964, and the bolls began to open on September 14, 1964. Boll samples were taken during the third week of October and from these samples seed weight, percentage of lint cotton, bolls per pound, and mean fiber length were determined. The sample was

hand-picked on October 26, 1964, and ginned at Locust Grove, Georgia, two days later. A 465 pound bale was made at the gin and this bale of the selected fiber was transported to the A. French Textile School and stored.

Characteristics of the Sample

Several pounds of fiber were removed from the bale for test purposes. This cotton was fluffed and stored under standard laboratory conditions for 24 hours. The standard sample was then tested on the Micronaire and the Digital Fibrograph. Results of these tests yielded averages of 4.11 micrograms per inch of fiber and a 2.5 percent span length of 1.056 inches, respectively. These averages, like those of the 1962 experimental cotton, are typical of most southeastern cottons.

The standard sample was hand-picked and is therefore much cleaner than machine-picked cotton. This fact, however, does not cause the fiber friction sample to be a special sample, because the friction study will concern itself with individual fibers only. The same reasoning applies for the occurrence of fewer broken and "spindled" fibers caused by a machine picker.

Comparison of Samples

The two samples of cotton which considered in this study, Empire WR from the 1962 and 1964 crops, were grown under the supervision of the Georgia Agriculture Experiment Station in fields near the station. The soils in these fields are of the same classification and have approximately the same amount of erosion. Cotton grown by the station is used for variety tests so all cotton is managed in the same manner. Empire WR

cotton grown by the station in 1962 and 1964 may, therefore, be said to be similar in relation to planting and crop management.

Weather conditions can have a great effect on the quality of a particular cotton crop. In examining the two growing seasons under consideration, it is believed that the 1964 season was slightly wetter than the 1962 growing period. This extra moisture during the later period did not, however, affect the quality or grade of the cotton grown during this season.

The 1962 crop of Empire WR cotton was machine-picked by a spindle-type picker. The 1964 crop, however, was hand-picked. Consequently, the appearance of the two samples differs quite significantly. This difference does not significantly affect the similarity of the two cottons as applicable to a study of fiber friction because such a study is concerned with individual fibers only, and not with the cleanliness or trash content of the entire sample.

Two standard fiber tests were conducted to further determine the physical similarities of the samples. These tests, the Micronaire fineness test and the Digital Fibrograph length test, gave the following results:

<u>Micronaire (mg per inch)</u>		<u>Digital Fibrograph (inches)</u>	
<u>1962</u>	<u>1964</u>	<u>1962</u>	<u>1964</u>
4.02	4.11	2.5% span length	1.043
		50.0% span length	0.489
		66.7% span length	0.365
			1.056
			0.445
			0.330

The Micronaire results, averages of ten observations for each crop,

are not significantly different, the difference between the results being only 2.2 percent of the higher average. Fibrograph results are expressed as a percentage of fibers which are equal to, or longer than, a stated length. The lengths shown above are averages of five samples of each of the two cotton samples. These lengths are very consistent for the two years, and the two cotton samples, therefore, have similar length characteristics.

The overall appraisal of the similarity of the Empire WR cotton grown by the Georgia Agriculture Experiment Station in 1962 and 1964 is that the two crops are sufficiently similar so that experimental conclusions describing the 1962 cotton are applicable to the 1964 crop.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

There is a significant difference in the number of convolutions per unit length between Empire WR cotton fibers of one-half, five-eighths, and one and one-fourth inch lengths; and fibers of three-fourths, seven-eighths, one, and one and one-eighth inch lengths.

A significant difference exists in the number of crimps per unit length in Empire WR cotton between lengths of one-half, five-eighths to one and one-eighth, and one and one-fourth inches.

Since the number of convolutions per unit length of cotton fiber significantly affects fiber-to-fiber friction, according to Adderley⁹, there is a probable difference in fiber-to-fiber friction between various staple lengths of Empire WR cotton attributable to the convolution factor.

The variety of Empire WR cotton selected and grown as a standard for fiber friction studies is physically typical of cotton varieties grown in the southeastern United States.

Recommendations

Cotton fiber convolutions are known to be some function of fiber maturity. This might be developed into an empirical relationship by observing the number of convolutions in a cotton fiber and then measuring its cross-sectional areas which are greater than those of the flat-

ter mature fibers. When this area and the number of convolutions per unit length for each of many cotton fibers are known, an equation could be developed. This equation might take the form

$$kA = \frac{l}{\text{convolutions per unit length}}$$

where k is an empirical constant and A is the cross sectional area of the fiber. In addition, a staple length constant or variable might be included in the equation.

Convolutions and crimps were observed in cotton fibers which had only been ginned after being picked. An interesting series of research experiments would be achieved by selecting fiber specimens after each of the steps of opening, picking, carding, spinning and weaving and using these as samples for a study of changes of convolutions and crimps, resulting from each processing stage. An investigation of this type might reveal a significant change in fiber shape attributable to the manufacturing processes.

APPENDIX

Table 1. Empire WR Variety Test Summary

Lint Yield Per Acre Produced at Four Georgia Locations			
	1962-1963 Average		1962-1963-1964 Average
	(lbs)		(lbs)
Athens	621		750
Calhoun	700		651
Midville	581		550
Plains	622		743
Average	631		674

Overall Yields Per Acre Produced at Two Georgia Locations During 1963				
	Acre Yield		Gin Turn- out %	Bolls Per Pound No.
	Seed Cotton (lbs)	Lint (lbs)		
Experiment	1994	754	37.8	55
Birdie	2964	1114	37.6	52

Table 2. Preliminary Fiber Tests on Empire WR Cotton

	Micronaire (micrograms per inch)		Digital-Fibrograph (2.5% span length, inches)	
	1964	1962	1964	1962
	4.1	4.1	1.024	1.062
	4.0	3.9	1.094	1.023
	4.1	4.1	1.035	1.053
	4.0	4.0	1.055	1.032
	4.2	4.0	1.070	1.047
	4.1	4.0		
	4.2	3.9		
	4.1	4.0		
	4.2	4.1		
	4.1	4.1		
Average	4.11	4.02	1.056	1.043

Table 3. Number of Convolutions in Seven Staple Lengths of Empire WR Cotton

Test Number	Fiber Length (inches)						
	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
1	51.0	44.0	63.0	69.0	72.0	113.0	77.0
2	43.0	52.5	65.8	75.0	9.10	81.0	85.5
3	21.0	58.0	75.5	62.0	80.5	81.0	71.5
4	22.5	45.0	88.0	70.0	67.5	95.5	113.5
5	40.0	38.5	87.5	83.5	74.5	95.5	55.0
6	38.0	49.5	61.5	80.5	99.0	100.5	105.0
7	27.0	75.5	55.5	69.0	76.0	104.5	80.5
8	30.0	46.0	57.0	87.0	86.5	66.0	74.5
9	32.5	37.5	81.0	84.5	85.5	120.5	106.0
10	21.5	38.0	51.5	61.5	103.0	86.5	80.5
11	32.5	51.5	73.0	67.0	68.0	73.5	123.5
12	37.0	42.0	67.5	78.0	70.5	79.0	57.0
13	28.0	59.0	79.0	60.5	90.5	80.5	54.5
14	46.5	37.5	53.5	78.5	78.5	74.5	61.0
15	41.0	48.0	51.0	81.5	87.0	84.0	127.0
16	49.5	39.0	62.5	70.0	83.0	91.5	90.0
17	32.5	62.5	58.5	94.5	70.5	116.5	109.0
18	38.5	49.0	79.0	67.5	77.0	103.5	88.5
19	29.0	71.5	52.0	81.0	92.0	110.0	82.0
20	48.5	33.5	51.5	62.5	86.5	94.0	111.5
21	34.0	42.5	59.0	85.5	93.0	89.5	112.8
22	49.0	38.0	64.0	70.0	85.5	83.0	68.5
23	30.0	40.5	46.5	68.5	122.5	97.5	77.0
24	41.0	48.0	52.0	75.5	97.5	86.0	85.5
25	34.5	47.5	78.5	78.5	77.0	101.0	71.5
Average	35.92	47.38	64.52	74.44	84.58	92.32	86.86

Table 4. Computed Data on the Convolution Factor

Test	Staple Length (inches)						
	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
Average number of convolutions per inch of fiber	65.4	71.9	91.5	84.8	83.6	83.9	67.9
Range of test values (highest-lowest)	30.0	38.0	36.5	25.5	35.5	54.5	58.5
Standard Deviation	10.18	12.13	13.48	9.30	11.66	16.34	18.11
Confidence intervals	(71.84 \pm 3.05)	(86.02 \pm 4.23)	(84.58 \pm 4.34)	(69.48 \pm 7.24)	(75.80 \pm 3.70)	(85.02 \pm 3.09)	(82.06 \pm 4.83)
Tolerance limits	(71.84 \pm 19.67)	(86.02 \pm 27.29)	(84.58 \pm 28.00)	(69.48 \pm 46.72)	(75.80 \pm 23.89)	(85.02 \pm 19.91)	(82.06 \pm 31.13)

Table 5. Number of Crimps in Seven Staple Lengths of Empire WR Cotton

Test Number	Fiber Length (inches)						
	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
1	10	10	11	12	14	16	14
2	11	10	10	14	20	21	18
3	8	8	13	14	17	19	17
4	12	9	13	15	15	19	23
5	7	14	11	18	17	19	24
6	12	10	12	14	18	23	17
7	9	11	11	15	14	22	15
8	10	14	13	12	17	16	19
9	10	10	14	18	16	22	19
10	8	9	9	13	16	18	18
Average	8	9	9	13	16	18	18

Table 6. Computed Data on the Crimp Factor

Test	Fiber Length (inches)						
	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
Average number of crimps per inch	19.4	16.8	15.6	16.5	16.4	17.3	14.7
Range of values (highest-lowest)	5	6	5	6	6	7	8
Standard deviation	1.70	2.00	1.57	2.11	1.83	2.45	3.13
Confidence intervals	(19.4 \pm .99)	(15.6 \pm .91)	(16.4 \pm 1.06)	(14.7 \pm 1.31)	(16.8 \pm 1.16)	(16.5 \pm 1.22)	(17.3 \pm 1.42)
Tolerance limits	(19.4 \pm 4.83)	(15.6 \pm 4.46)	(16.4 \pm 5.19)	(14.7 \pm 8.88)	(16.8 \pm 5.68)	(16.5 \pm 5.98)	(17.3 \pm 6.96)

Table 7. Examples of Calculations

Raw Data for Crimps in One Inch Fiber	
<u>x</u>	
14	
20	
17	$\bar{x} = 16.4$
15	$\bar{x}/\text{in.} = 16.4$
17	$\bar{x}^2 = 268.96$
18	$\sum (x)^2 = 2720.00$
14	$s = 1.83$
17	
16	
<u>16</u>	

Confidence interval for $\alpha = 0.05$ and 9 degrees of freedom.

$$\bar{x} \pm t_{/2, n-1} \frac{s}{n} = 16.4 \pm (1.833) \frac{1.83}{3.16} = 16.4 \pm 1.06$$

Tolerance limit for $\alpha = 0.10$, $\gamma = 0.95$, and a sample size of 10.

$$\bar{x} \pm Ks = 16.4 \pm 2.839(1.83) = 16.4 \pm 5.19$$

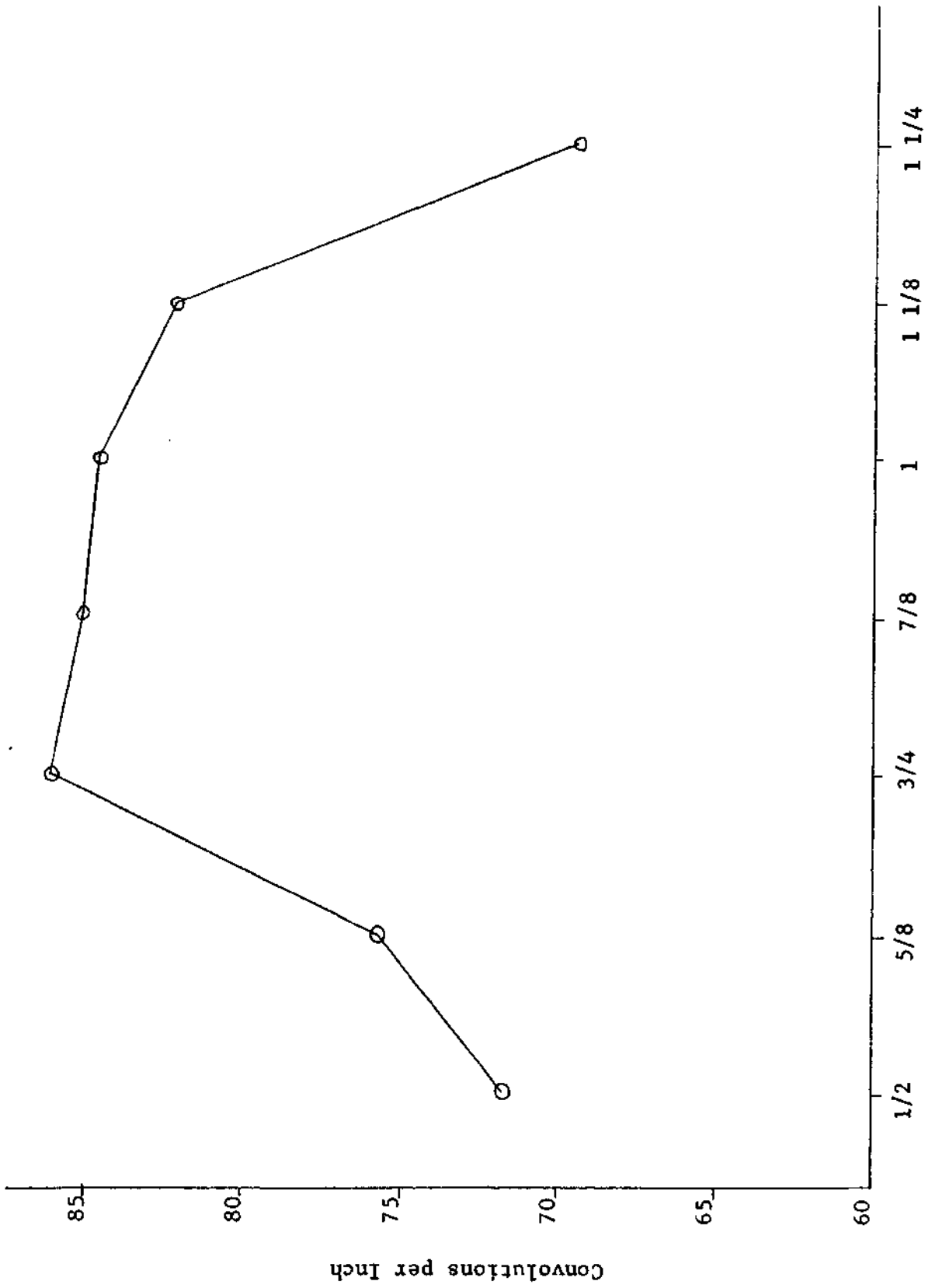


Figure 2. Convolutions per Inch as a Function of Staple Length

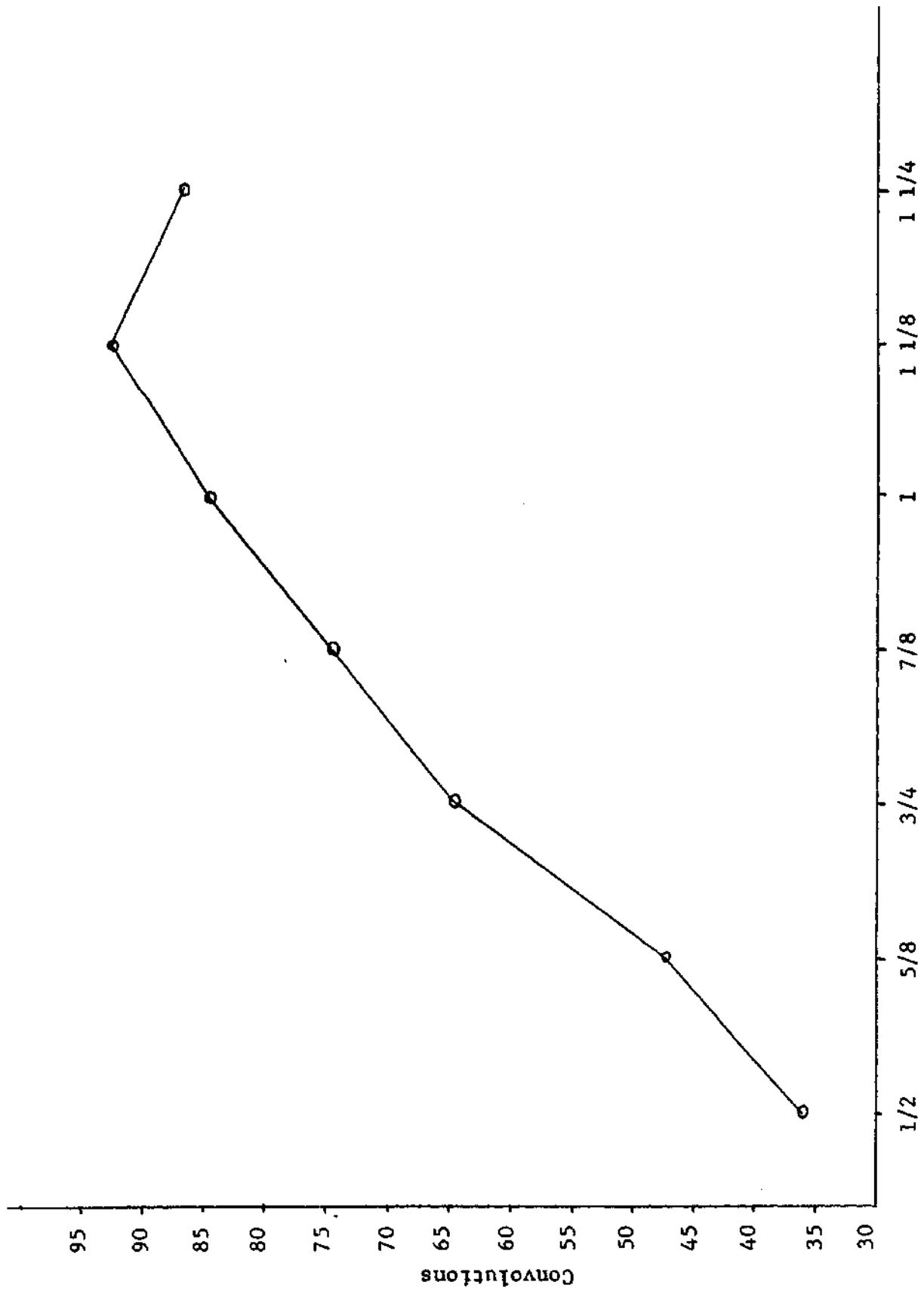


Figure 3. Convolutions as a Function of Staple Length

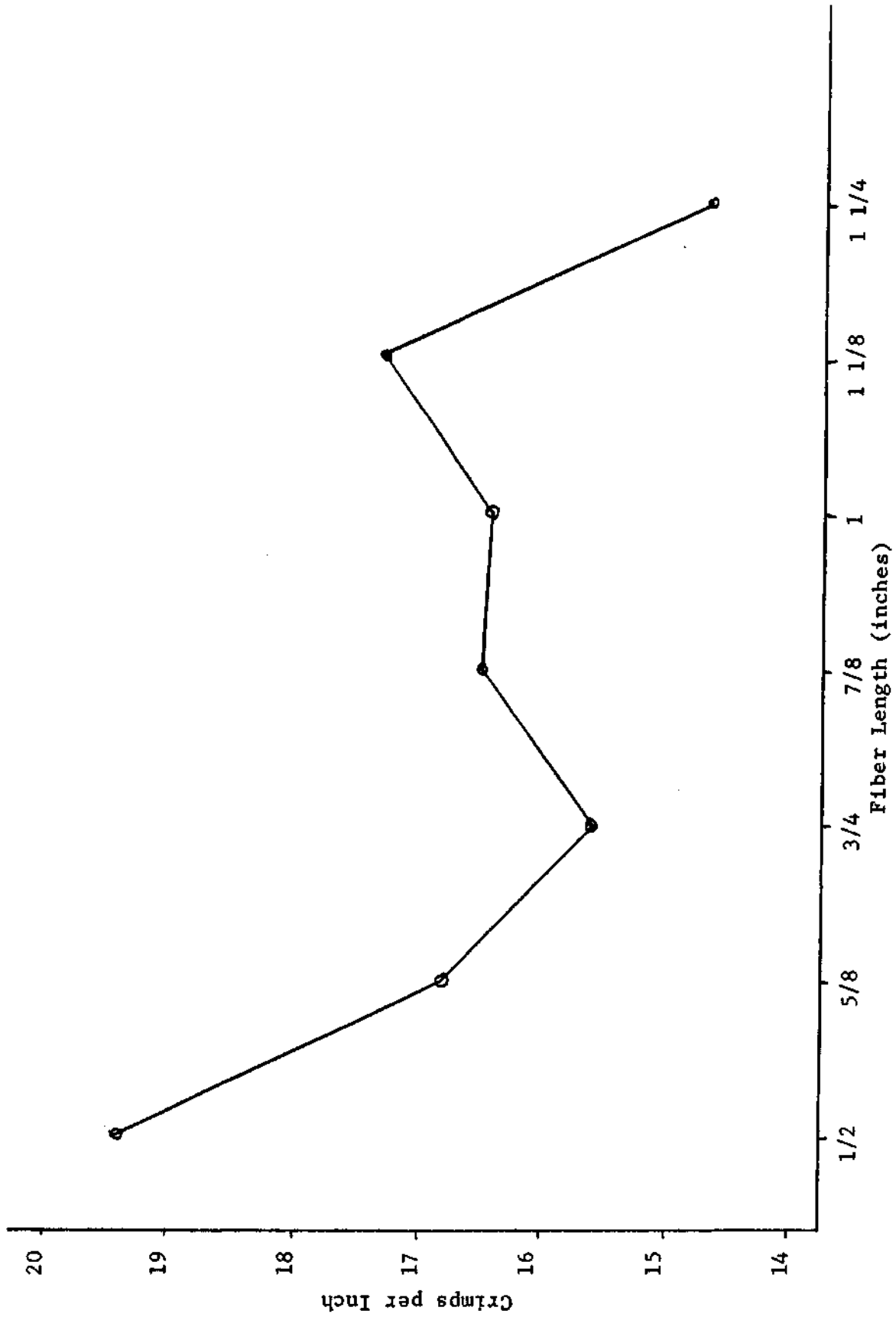


Figure 4. Crimps per Inch as a Function of Staple Length

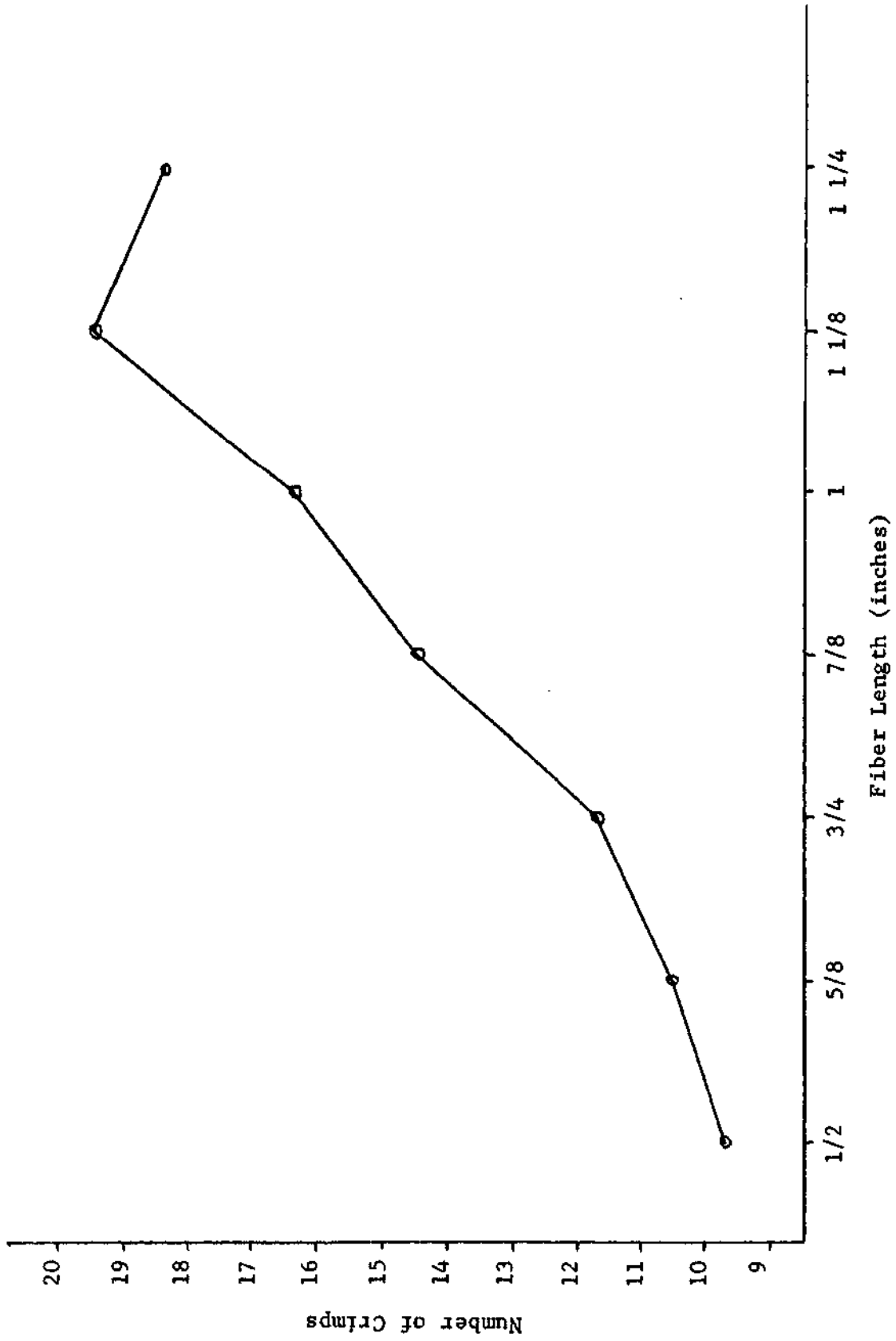


Figure 5. Crimp as a Function of Staple Length

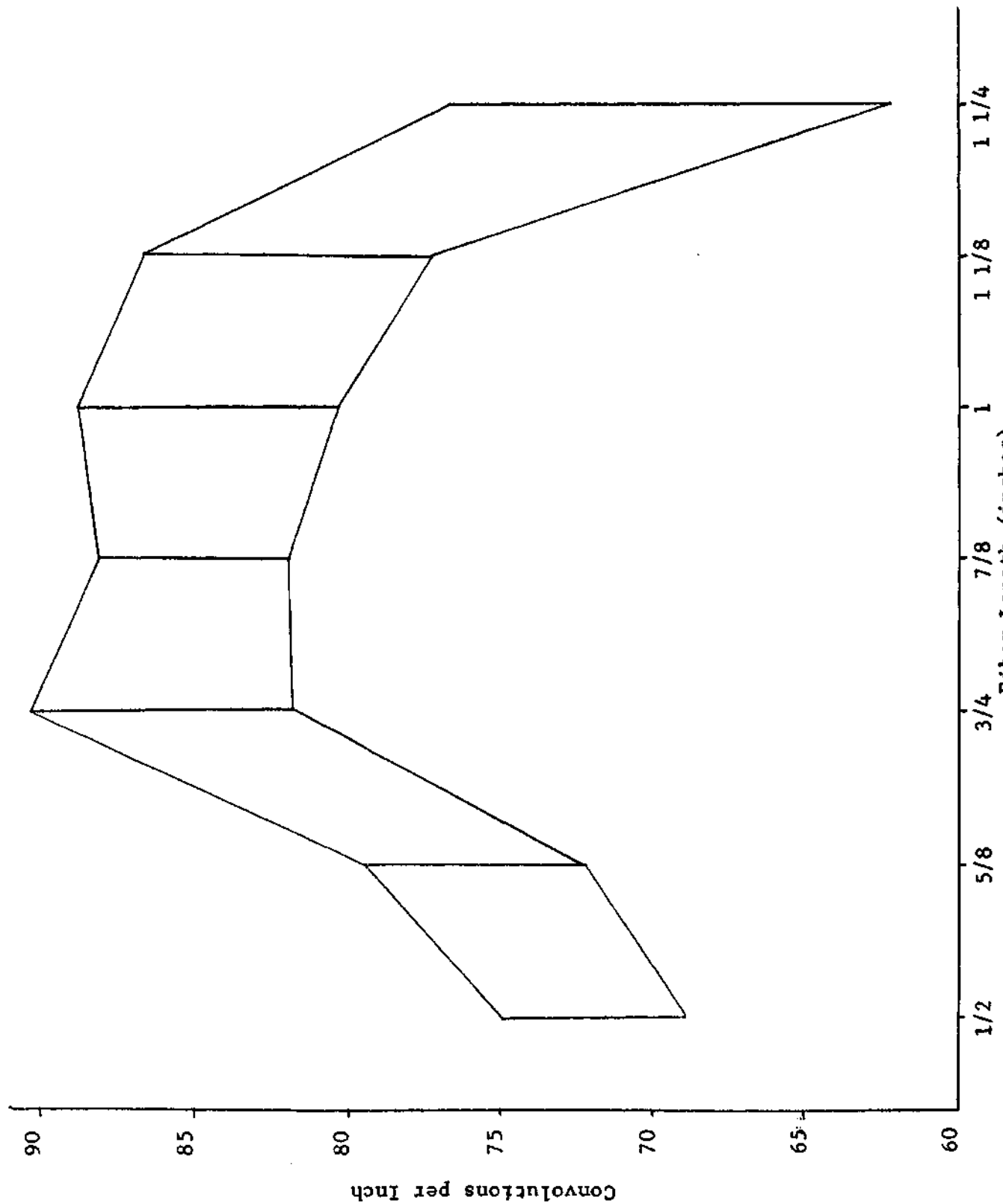


Figure 6. Confidence Intervals for Convolutions per Inch as a Function of Staple Length

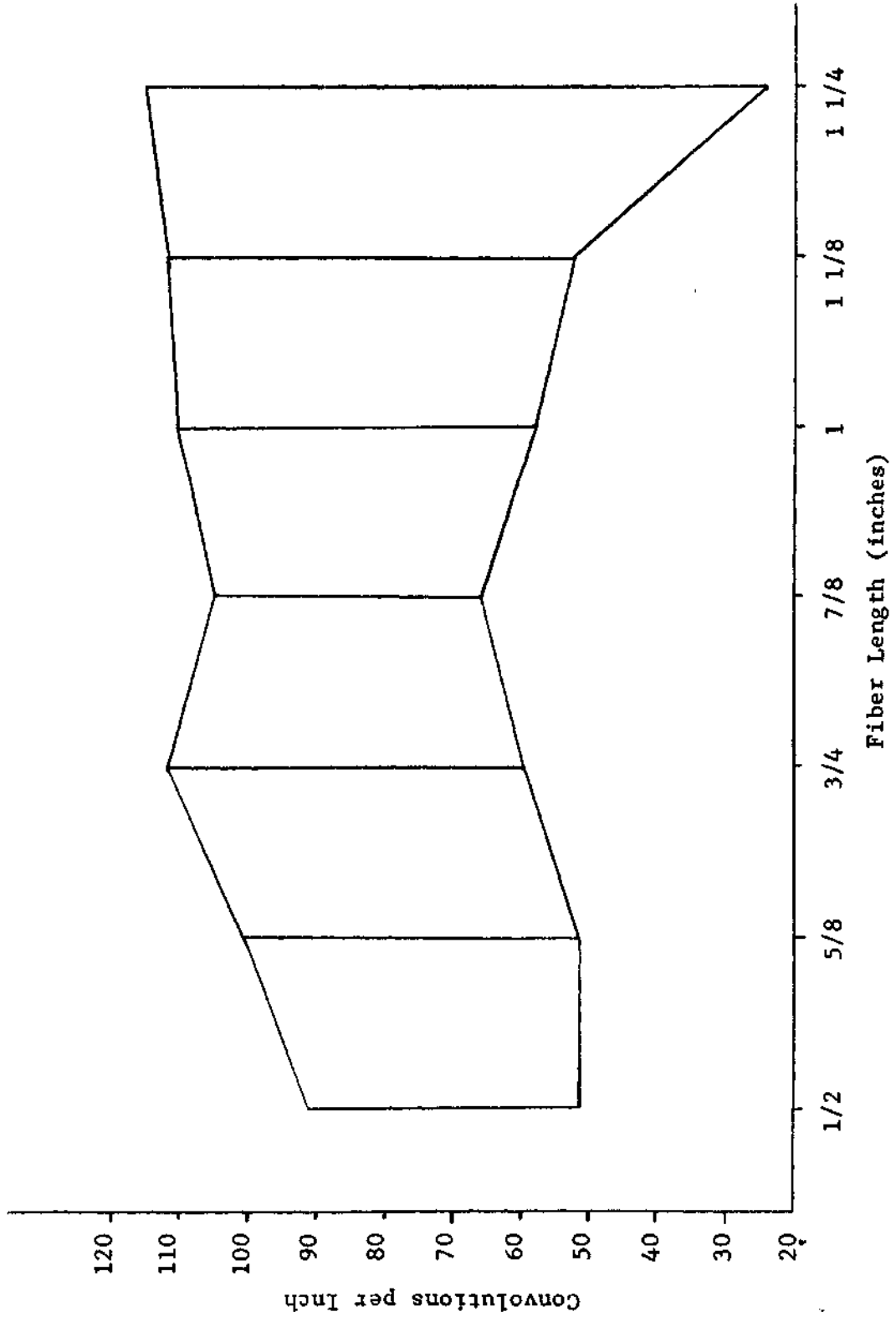


Figure 7. Tolerance Limits for Convolutions per Inch as a Function of Staple Length

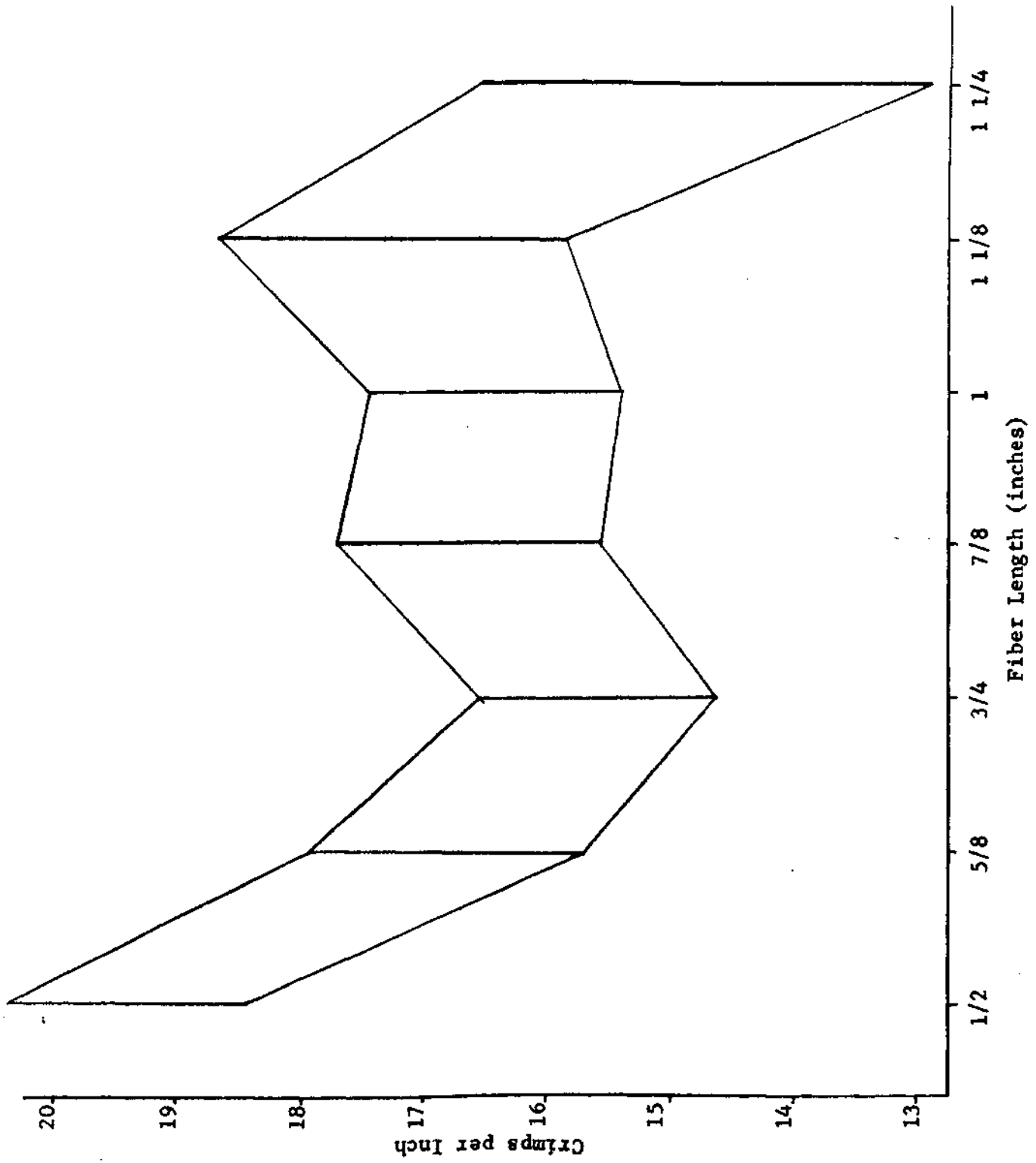


Figure 8. Confidence Intervals for Crimps per Inch as a Function of Staple Length

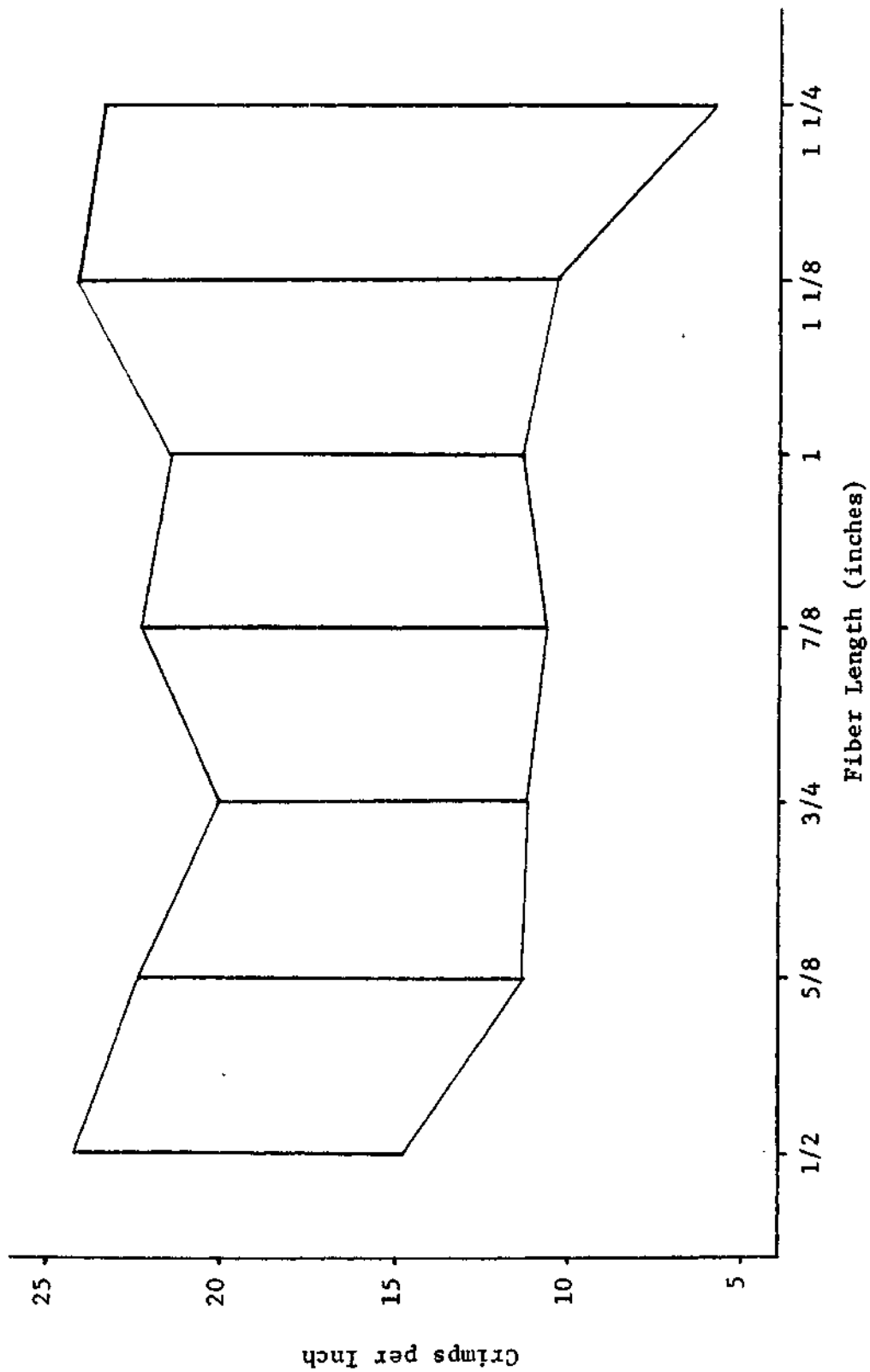


Figure 9. Tolerance Limits for Crimps per Inch as a Function of Staple Length

BIBLIOGRAPHY

REFERENCES CITED

1. The Notebooks of Leonardo da Vinci, English translation by E. McCurdy, 2 vol., 1938.
2. Amontons, "De La Resistance Causee Dans les Machines", Memories de l'Académie Royale des Science, (1699), 206.
3. Coulomb, "Theorie des Machines Simples, En Ayant Egard au Frottement de Leur Parties, et a la Roideur des Cordages", op. cit., (1785), 161.
4. Morin, "Nouvelles Experiences sur le Grottement", Institute de France Académie Royale des Sciences, 1831.
5. P. L. Copeland and E. J. Scheibner, "Electron Diffraction Studies of Friction", Illinois Institute of Technology, A. F. Technical Report OSR-TR-54-18, June, 1954.
6. Bowden, "The Area of Contact between Stationary and Moving Surfaces", Procedures of the Royal Society, 169, (1938), 311.
7. J. H. Langston and W. T. Rainey, "A Literature Survey on Fiber Friction", Clemson Agricultural College, 1954.
8. J. M. Whitney, "Analytical and Experimental Study of the Mechanisms of Monofilament Fiber Friction", A. F. Technical Report RTD-TDR-63-4127, Part 1, December, 1963.
9. A. Adderley, "The Clinging Power of Single Cotton Hairs", Textile Institute Journal, 13, (1922), 249-255.
10. S. M. Betrabet, K.P.R. Pillai, and R.L.N. Iyengar, "Convolution-Angle of Cotton Fibers", Journal of Scientific and Industrial Research, 19A, (February, 1960), 91.
11. J. G. Inyman, "Cortical Bilateral Structure and Wool Crimp", Textile Research Journal, 10, October, 1963.
12. C. B. Lanstreet, "A Study of Length Distributions in Fibre Array Groups", Textile Bulletin, 3, 88, (1962), 66-69.
13. J. A. Goodwin, "The Use of Tollens Reagent in the Microscopical Study of the Surface Characteristics of Natural and Synthetic Fibers", Textile Research Journal, 10, October, 1963.

OTHER REFERENCES

- Balls, W. L., Studies of Quality in Cotton, 1928.
- Balls, W. L., The Development and Properties of Raw Cotton, 1915.
- Bobeth, W., "Determination of Cotton Maturity", Natural and Synthetic Fibers Yearbook, (1960), 821.
- Bowden, F. P., Tabor, D., The Friction and Lubrication of Solids, 1954.
- Bowker, A. H., Lieberman, G. J., Engineering Statistics, 1961.
- Buckman, O. H., N. C. Brady, The Nature and Properties of Soils, MacMillan Company, 1960.
- Chippindale, P., "Replication of Textile Fibers in Electron Microscopy", ibid., 1205.
- "Cotton Varieties Planted, 1959-1963", U. S. Agricultural Marketing Service, Cotton Division, 1963.
- Encyclopedia Britannica, vol. 9, 1962, 840A.
- "Frictional Properties of Cotton Fibers", Georgia Tech Research Proposal, U. S. Department of Agriculture, February 19, 1964.
- Grant, J. N., E. C. Kingsberry, R. H. Tsoi, "Heating, Cleaning, and Mechanical Processing Effects on Cottons, Part III: Fiber Properties and Spinning Behavior", Textile Research Journal, 33, no. 10, October 1963.
- Herale, J. W. S., Physical Methods of Investigating Textiles, Textile Book Publishers, Inc., New York, 1959.
- Iskhakov, Sh., "Treatment of Cotton Fibre with Organic Solvents to Increase the Friction between the Single Fibres", Izvest Vysshikh Ucheb, Zavednii, Tekhnol. Tekstil. Prom., 16, No. 3, (1960), 30.
- Pope, C. J., Cotton Fibers, 1955.
- Rebenfeld, L., "Fiber Properties Affecting Mills", presented at the Cotton Marketing Conference Research Clinic, May 16, 1961.
- Scheier, S. C. and W. J. Lyons, Textile Research Journal, 34, (1964), 410.
- Schwarz, E. R., Textiles and the Microscope, 1934.

Shiloh, M., "A Modification of the Method for Defining and Measuring Crimp of Textile Fibers", Textile Research Journal, 31, no. 12, (1961), 999.

Stoves, J. L., Fibre Microscopy, 1957.

Tabor, D., Friction in Textiles, Textile Book Publishers, Inc., New York, 1959.

Trillat, J. J., Sella, C., "Electron Microscopical Studies of Synthetic and Natural Polymers", Natural and Synthetic Fibers Yearbook, (1961), 305.

Woods, H. J., Physics of Fibres, The Institute of Physics, London, 1955.

1963 Field Crops Variety Trials, University of Georgia College of Agriculture, Agriculture Experiment Station, (1963), 23, 27.