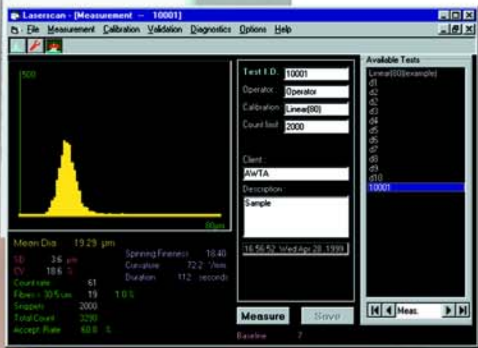

AWTA LIMITED

LASERSCAN

a New Technology for a New Millennium

Cover Depiction - Evolution of Fibre Fineness Measurement

Early interest in the fineness of wool fibres was centred on wool top. IWTO initially defined fibre fineness in terms of the weight in milligrams of 10 metres of wool fibres at a regain of 18.25%. The method used (called the Gravimetric Method) was developed in1931 and relied upon weighing a defined number of wool fibres cut to a known length, and expressing the mean fineness in terms of the weight of a standard length at a standard regain.

This method, and consequently this definition, was subsequently found to have a number of limitations. In the period 1932 ñ 1954 an increasing emphasis was placed on the use of the Projection Microscope, which defines wool fibre fineness in terms of the mean width of the projected image of the fibre. The Projection Microscope was more precise than the Gravimetric Method and moreover it also provided information about the fineness distribution. ASTM produced a draft specification for the measurement of wool fibre fineness, based on the Projection Microscope, in 1950. The first IWTO Specification for the instrument was approved in 1954.

Development of the Airflow began in 1941. Initially it was hoped that the Airflow instrument could provide a direct estimate of fibre fineness. However, this proved to be impossible, and the Airflow method, published in 1955, relied on calibrating the instrument using wool tops. The fineness of the calibration tops was determined using the Projection Microscope.

An international specification for the determination of Mean Fibre Diameter of wool tops using the Airflow instrument was approved by IWTO in 1960. While the instrument did not provide any information about distribution of fibre fineness its precision, coupled with its rapidity, meant that the Airflow instrument quickly displaced the Projection Microscope for the routine measurement of the fineness of wool top. The application of the Airflow instrument was extended to raw wool after the acceptance of a specific test method (IWTO-28) in 1971.

The Airflow instrument has served the Wool Industry well. Its wide use and acceptance has meant that *de facto*, in commercial as well as technical terms, it effectively defines fibre fineness, despite the fact that it is still calibrated by reference to the Projection Microscope. However, while the industry has found it convenient to overlook the fact that the Airflow instrument provides no information about fineness distribution, it has never lost interest in developing rapid techniques which provide this additional information.

CSIRO commenced development of the LASERSCAN in 1971, examining the light scattering properties of single fibres of wool, hair, and jute, and also filaments of nylon, terylene and glass when they intersected a beam of coherent light provided by a Helium-Neon laser. In 1976 CSIRO described the design principles, construction and operation of an instrument based on this effect, where the fibres, presented as snippets, were suspended in a fluid and transported through a measurement cell where the snippets intersected the laser beam. The precursor to the LASERSCAN, the FDA, emerged in the early 1980ís. The modern LASERSCAN evolved from this instrument and IWTO approved an international test method for it in 1995 (IWTO-12).

LASERSCAN offers all the advantages of the Airflow, but the additional advantages of even more information about wool fibre characteristics such as distribution in diameter, comfort factor and curvature.

AWTA Ltd - SEPTEMBER, 1999

SIROLAN™ LASERSCAN

a New Technology for a New Millennium

a Quick Tour

Measurements:

- Mean Fibre Diameter
- Standard Deviation of Diameter
- Coefficient of Variation of Diameter
- Diameter Distribution Histograms
- Comfort Factor
- Fibre Curvature

Precision:

- Better than Projection Microscope
- Better than Airflow
- Better than OFDA

Interferences:

- Unaffected by:
  - Medullation
  - Fibre Curvature
  - Variations in Distribution
  - Ellipticity
  - Colour

Calibration:

- Only one Calibration is needed for both wool sliver and greasy wool
- Calibrated using Interwoollabs International Standards

Processing:

- For Australian raw wool LASERSCAN is more highly correlated with Airflow than competing instruments and shows no apparent average bias over the range of diameters normally encountered

Benefits:

- More accurate
- More information
- Better prediction of processing performance

CONTENTS

AWTA LIMITED

INTRODUCTION

The fineness[1] of wool fibres is of fundamental importance to spinners and weavers. The finer the fibres, and the fewer the number of fibres present in a cross section of yarn produced from the fibres, the more flexible the yarn. These factors are major determinants of the quality of wool fabrics, and this is why the fineness of wool is such a significant determinant of the value of raw wool.

The International Wool Textile Organisation[2] (IWTO) has developed 4 individual Test Specifications, based on 3 different instruments, each of which may be used to issue IWTO Certificates for Mean Fibre Diameter of raw wool and/or wool sliver. These methods are:

- **IWTO-6:** *Method of Test for the Determination of the Mean Diameter of Wool Fibres in Combed Sliver using the Airflow Apparatus;*
- **IWTO-12:** *Measurement of the Mean and Distribution of Fibre Diameter using the LASERSCAN Fibre Diameter Analyser;*
- **IWTO-28:** *Determination by the Airflow Method of the Mean Fibre Diameter of Core Samples of Raw Wool; and*
- **IWTO-47:** *Measurement of the Mean and Distribution of Fibre Diameter of Wool using an Optical Fibre Diameter Analyser (OFDA).*

LASERSCAN (IWTO-12) and OFDA (IWTO-47), both accepted in 1995, are the most recent additions to this set of specifications. Amendments to the IWTO Core Test Regulations, and the IWTO Blue Book, to facilitate the commercial application of both of these new Specifications were accepted at the IWTO Congress in Nice in December 1996. However, a constraint was applied requiring the issuing of an Airflow (IWTO-28) Certificate to accompany each LASERSCAN or OFDA certificate. In June 1999 the Florence Congress of IWTO removed this constraint for the certification of Mean Fibre Diameter of Australian wool, thereby clearing the way for any licensed IWTO Laboratory in Australia to replace Airflow as its standard service with LASERSCAN or OFDA. AWTA Ltd has elected to use LASERSCAN and this transition will occur in July 2000.

First established as an IWTO Specification in June 1975, Airflow has been the wool industry's primary method for determining the Mean Fibre Diameter of raw wool. The development of the LASERSCAN not only provides an improved measurement of this important characteristic, but also provides additional information that has not previously been readily available. The general availability of this information for Australian wool will further assist the world wool industry in producing better quality products from Australian greasy wool.

The implementation of LASERSCAN as the standard service for Australian wool is a major change, which has some short term and long term implications. This document is intended to assist all sectors of the industry in their understanding of this new technology and the information it provides.

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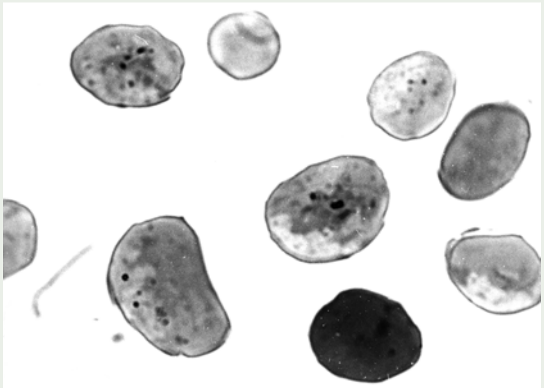
[1] The term ìMean Fibre Diameterî in the context of wool fibres is misleading, since it implies that wool fibres have a circular cross section. In describing the thickness or thinness of wool fibres it is more accurate to use the term ìfibre finenessî rather than ìfibre diameterî. The word ìfinenessî does not imply any particular geometry for the shape of the cross section. However, because of the extent of its general usage, ìfibre diameterî is used interchangeably with ìfibre finenessî throughout this document.

[2] IWTO provides a forum for establishing standardised test procedures (IWTO Test Specifications), regulations governing the use of these procedures (IWTO Regulations), and procedures for arbitrating disputes over commercial transactions involving raw wool, wool sliver and wool yarns (the IWTO Blue Book). As such, IWTO is pivotal in providing a technical and commercial framework for international and intranational trade involving wool.

Mean Fibre Diameter

Wool fibres are not uniform cylinders, nor is the thickness of the fibres exactly the same. The fibre cross-section is roughly circular, but can vary from ovoid (egg-shaped) to elliptical and a range of shapes in between. Some fibres actually have concave cross-sections. The magnified cross sections of some fibres selected from a 19-micron top[1] are shown below (Figure 1). Coarser wool can exhibit even greater variation than is illustrated here. This non-uniform geometry means that defining Mean Fibre Diameter (MFD) is not as simple as it may at first seem.

FIGURE 1: Fibre Cross-sections



Consider these fibre cross sections, and the range of shapes exhibited. How then do we determine the Mean Fibre Diameter? Clearly, if we use a ruler to measure the "diameter" of these images, the "diameter" we obtain for each image will depend where we place the ruler. We could of course use a ruler to measure a very large number of transects across each fibre cross section, and then calculate the average of all these transects, but that would be unbelievably tiresome. And in doing so, we would not have taken account of any variation in the dimensions of the cross section along the length of each fibre. We could only do this by taking a very large number of cross sections and making a large number of measurements – an even more tedious exercise.

Alternatively, we could define the fibre fineness in terms of the area of the cross section. Once again, if conducted manually, the measurement would be slow and tedious because many cross sections would have to be measured to obtain a reasonable estimate of the "area" or fineness of each fibre, and thus the average fineness of the sample.

Clearly, if fibre fineness is to be measured, the definition of fibre fineness must be related to some geometrical dimension of the fibre. There are effectively only four geometrical dimensions that are suitable. These are:

- the area of the cross section;
- the width of a 2-dimensional projected image;
- the area of the surface; or
- the area of a 2-dimensional projected image.

The Wool Industry has chosen to define Fibre Diameter in terms of the average thickness or width of a two-dimensional projected image of a large number of fibre snippets[2], measured using a Projection Microscope (IWTO-6). But what is a snippet and why measure Mean Fibre Diameter using snippets?

Within any mass of wool there is considerable variation in fibre fineness between fibres and along the length of individual fibres. To complicate things even further, there is also variation in the lengths of individual fibres. Any measurement of fineness must take this variation into account. The method used to obtain the sample to be measured is therefore of paramount importance.

Measuring fibre snippets is one way to take account of the variation of fibre length, as well as the variation in thickness along and between fibres. Fibre snippets are short lengths of fibre (0.8 - 2 mm long) cut from individual fibres at random positions along the length of the fibres. The precise mechanism for doing this generally involves using a mini-core (in the case of raw wool) or a microtome (in the case of wool sliver). The key issue is the randomness inherent in the sampling. Using these techniques the population of

[1] Photograph provided by Peter Turner, CSIRO Division of Wool Technology, Belmont, Victoria, Australia

[2] This choice is fundamentally one of convenience, because in practice it is the simplest and fastest way to obtain a direct measurement of the fineness of the fibres. Measurements based on fibre cross-section first require cross-sections to be obtained. The accuracy of the measurement is then determined by whether or not the cross-sections are taken perpendicular to the longitudinal axis of the fibre. Any deviation from perpendicular will distort the shape of the cross-section and make it increasingly elliptical. The fineness of wool fibres and the curvature of the fibres makes obtaining such cross-sections extremely difficult.

snippets so obtained will be biased towards the longer fibres i.e. more snippets will be obtained from longer fibres. Therefore, it is only necessary to measure the width of each snippet once, at a point randomly located along its length, and calculate the average of all these individual measurements, to obtain a reliable estimate of the average thickness, or the Mean Fibre Diameter of the wool. In practice, not all snippets need to be measured - a sample selected at random from the total population of snippets is usually sufficient. In scientific language, the Mean Fibre Diameter of wool is therefore a length-weighted mean.

The fibre snippets are spread on a glass slide in a mounting fluid under a glass cover-slip. They are magnified using a Projection Microscope and the widths of the magnified images of the snippets are measured using a graduated scale (basically a ruler). Care is taken to ensure that the snippet is in focus, and each snippet is measured only once.

Table 1: Distribution Data

Class Interval (Microns)	Mid-point (Microns) d	Number of Snippets n	% of Snippets F	d x n	d^2 x n
0-2	1	0	0.000	0	0
2-4	3	0	0.000	0	0
4-6	5	0	0.000	0	0
6-8	7	1	0.025	7	47
8-10	9	67	1.675	603	5427
10-12	11	818	20.450	8998	98978
12-14	13	1336	33.340	17368	225784
14-16	15	1066	26.650	15990	239850
16-18	17	448	11.120	7616	129472
18-20	19	159	3.975	3021	57399
20-22	21	55	1.375	1155	24255
22-24	23	22	0.550	506	11638
24-26	25	10	0.250	250	6250
26-28	27	6	0.150	162	4374
28-30	29	5	0.125	145	4205
30-32	31	3	0.075	93	2883
32-34	33	2	0.050	66	2178
34-36	25	1	0.025	35	1225
36-38	37	1	0.025	37	1369
38-40	39	0	0.000	0	0
	Totals	**4000**	**100**	**56052**	**815336**

The procedure followed is designed to ensure that the point at which each snippet width is measured is randomly located along the snippet. Because the magnification factor is known, these measurements can be readily converted into actual dimensions. For convenience, the Wool Industry expresses these dimensions as micrometres (microns). This results in values of fineness ranging from 10 to 50 micrometres (microns), where one micron is equivalent to one millionth of a metre.

Diameter Distribution Histogram

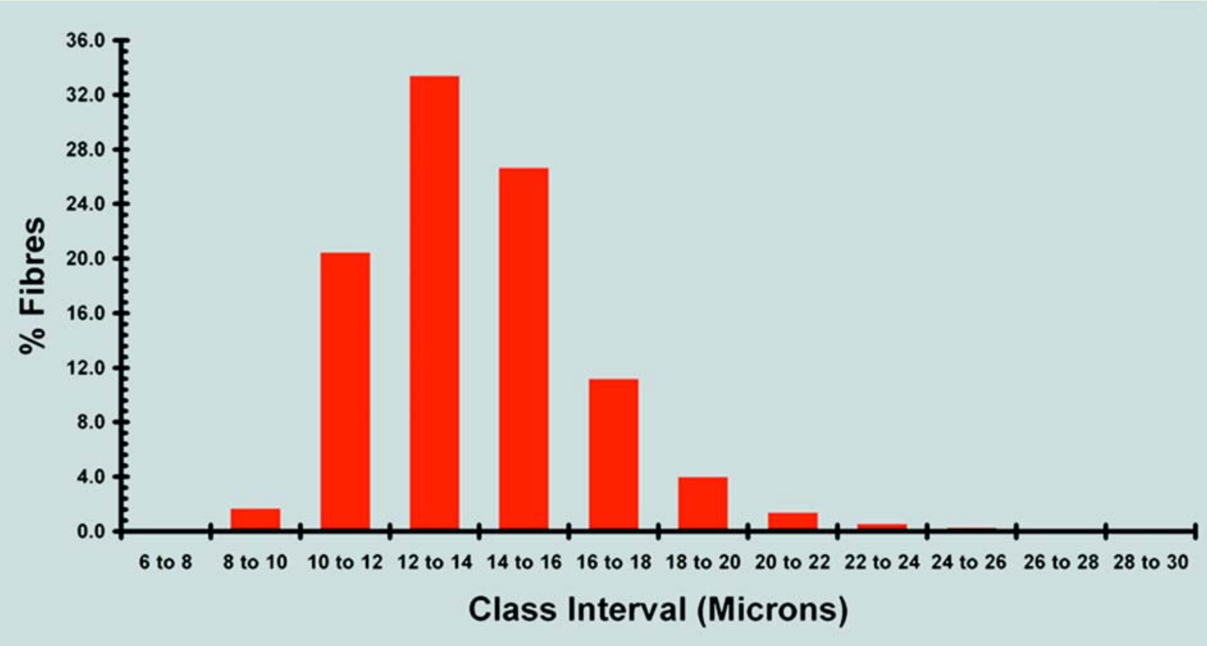
Measurements made on individual snippets using a Projection Microscope are classified into class intervals. A class interval is a range of diameters within which the measurements lie. The Projection Microscope technique uses class intervals of 2 microns. By recording the number of measurements that fall within each class interval, a diameter frequency distribution table is developed (see Table 1).

This frequency distribution table provides the information required to construct a pictorial image of the range of diameters and their relative proportions in the wool from which the fibre snippets were obtained. The class intervals are plotted on one axis and the numbers of fibre snippets (or their frequency expressed as a percentage) on the other axis. It is usual to use solid bars or lines to illustrate the number of fibres or their frequency. The Diameter Distribution Histogram derived from the information in the table is shown in Figure 2.

Note that in Figure 2, the histogram uses the percentage of fibre snippets rather than the number of snippets. Although either is satisfactory, in practice the number of fibre snippets can vary quite substantially and this makes comparisons of different histograms quite difficult. Using the percentage overcomes the difficulty.

In the particular situation illustrated, the largest snippet proportion (approximately 33%) has diameters in the range 12 to 14 microns. However this example of very fine wool has a small number of fibres in the range 24 to 26 microns.

Figure 2 : Diameter Distribution Histogram



Calculating the Mean Fibre Diameter (MFD) from a Diameter Distribution Histogram is a relatively simple exercise. The calculation is illustrated in the table on the previous page.

For each class interval, select the middle of the range (for example for 12 to 14 microns select 13 microns) and multiply this by the number of fibre snippets. Add the products so obtained for all the class intervals and then divide by the total number of fibre snippets. For this example:

$$MFD = \frac{\sum d \times n}{\sum n} = \frac{56052}{4000} = 14.0\,microns$$

Standard Deviation

The Standard Deviation of Fibre Diameter (SD) is a measure of the dispersion or spread of the distribution. If the distribution is very narrow (the range from the highest to the lowest diameter is small) then, for the same Mean Fibre Diameter, the Standard Deviation will be smaller. Conversely, if this range is large then the Standard Deviation will be larger.

This is illustrated in Figure 3 on the next page, where two idealised symmetrical Distribution Histograms are shown[1], each with the same Mean Fibre Diameter, but with different Standard Deviations. To present this more simply, the histograms are shown as continuous curves, instead of solid bars as in the first example above.

In this illustration it has been assumed that the same number of fibre snippets has been measured in both cases, and therefore the areas under both curves are actually identical. Note that the curve with the higher Standard Deviation is both wider and flatter.

Calculation of the Standard Deviation (SD) from the distribution data is a little more complex as it also involves a further calculation in multiplying the square of the diameter by the number of fibre snippets in each class interval. From the earlier table (Table 1):

$$SD = \sqrt{\frac{\sum n \times d^2 - \frac{\left(\sum n \times d\right)^2}{\sum n}}{\sum n \; - \; 1}}$$

$$= \sqrt{\frac{815336 - \frac{(56052)^2}{4000}}{4000 \; - \; 1}}$$

$$= 2.73\,microns$$

[1] Actual Distribution Histograms for wool rarely exhibit this symmetrical shape. Usually they are skewed to the right.

Figure 3 : Standard Deviation

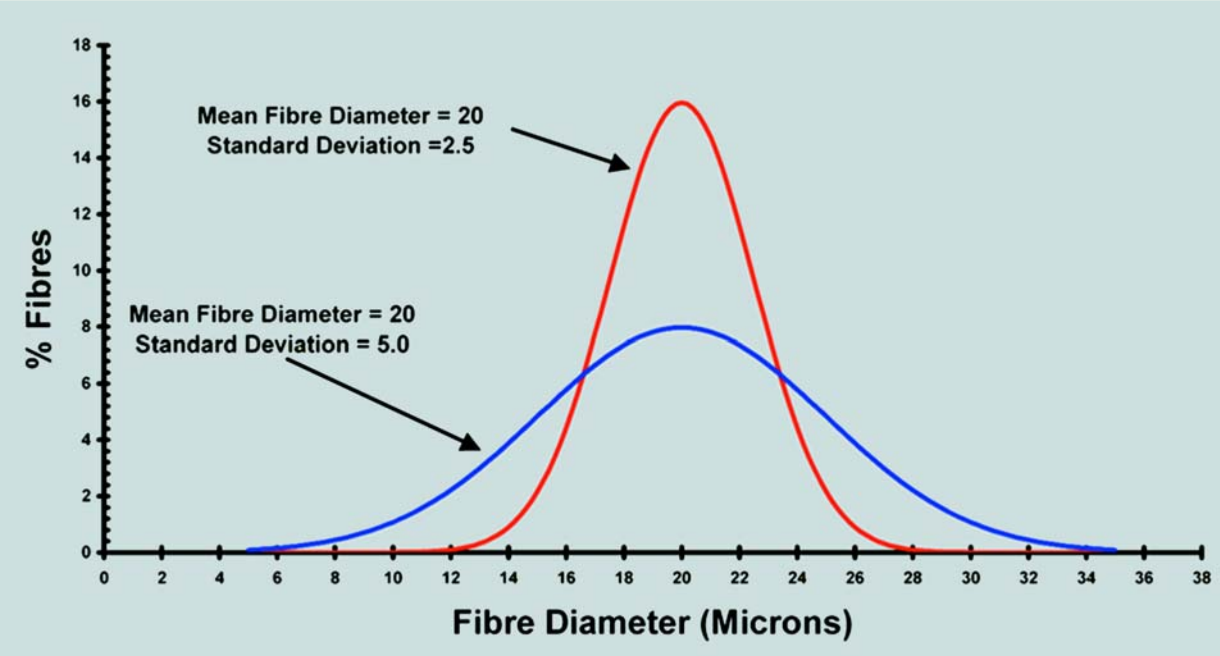
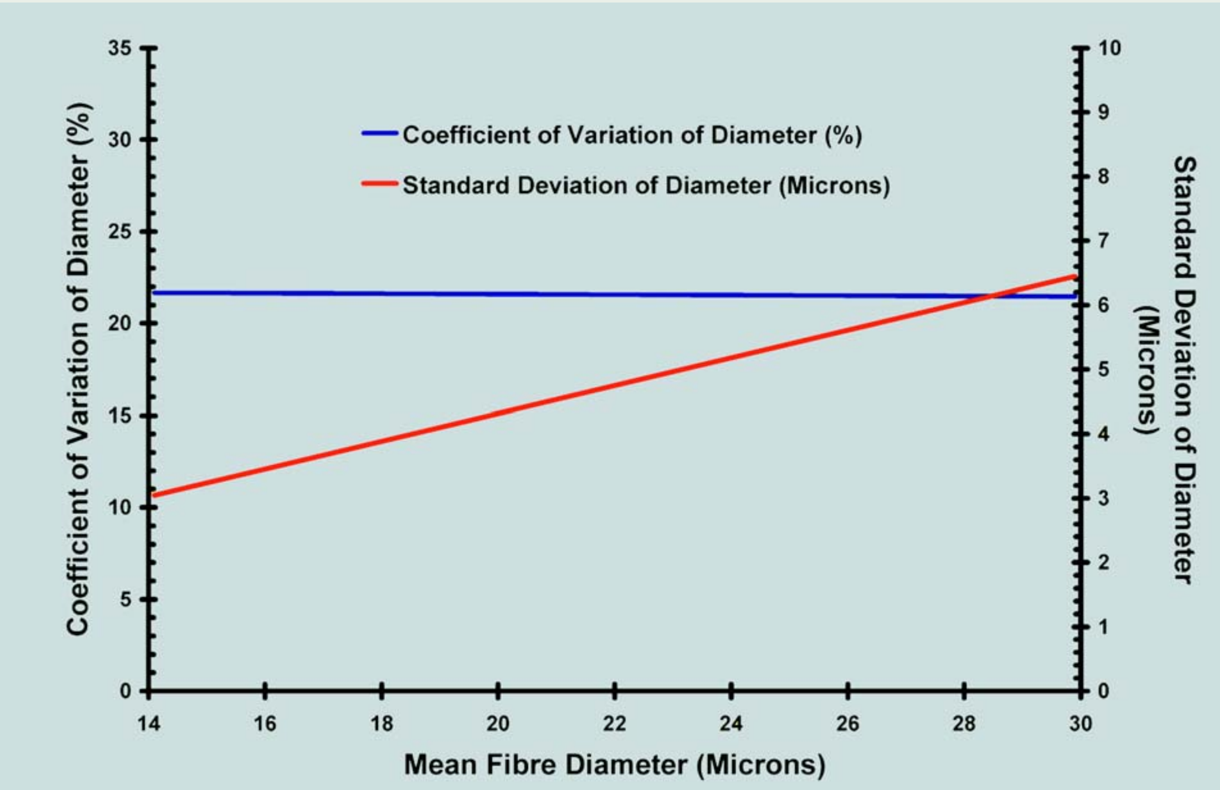


Figure 4 : Coefficient of Variation



Coefficient of Variation of Fibre Diameter

While the Standard Deviation is useful in describing the dispersion of a Fibre Diameter Distribution it is of limited usefulness in comparing different lots of wool, unless the Mean Fibre Diameters are identical. As the Mean Fibre Diameter of wool increases, so does the Standard Deviation.

In part this is due to the fact that the diameter distribution of wool fibres is rarely symmetrical. Most distributions are skewed towards the coarse end of the distribution. This must occur because as the Mean Fibre Diameter is reduced, the cellular structure of the wool fibres becomes a limiting factor determining the diameter of the finest fibres in the distribution.

Commercial use of distribution statistics requires a measure of dispersion that is comparable, even for different Mean Fibre Diameters. The Coefficient of Variation of Diameter (CVD) is such a measure.

The Coefficient of Variation (CVD) is derived from the Standard Deviation (SD) and the Mean Fibre Diameter (MFD) as follows:

$$CVD = \frac{SD}{MFD} \times 100 = \frac{2.73}{14.0} \times 100 = 19.5\,\%$$

Because the Standard Deviation is linearly related to Mean Fibre Diameter the Coefficient of Variation is, on average, independent of the Mean Fibre Diameter.

This is illustrated in Figure 4 showing the dependency of Coefficient of Variation of Diameter and Standard Deviation of Diameter on Mean Fibre Diameter for sale lots of Australian wool. The illustration is based on measurement of 2500 Australian sale lots during 1998/99.

Note that over the range of diameters in this illustration the Standard Deviation is steadily increasing. However the Coefficient of Variation of Diameter is essentially constant.

The lines in the illustration are average conditions. Individual sale lots will vary above and below these lines. The constancy of the average Coefficient of Variation of Diameter provides a benchmark for ranking individual sale lots using this particular measurement.

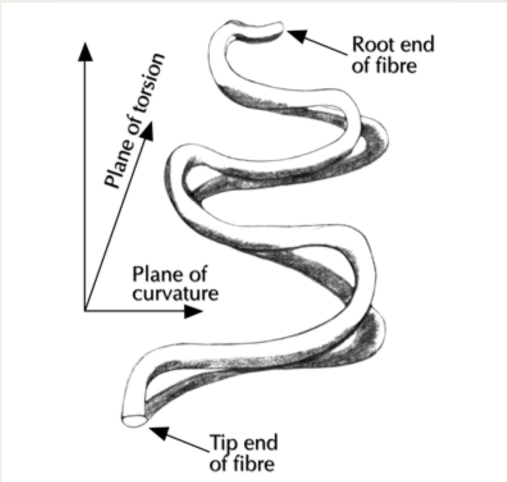
Curvature

The crimp of wool fibres has an impact on efficiency in top making and spinning, yarn properties and the structural and tactile properties of fabrics. This characteristic is of considerably less direct importance in processing and product performance than fibre fineness or fibre length. However, if its impact can be reliably predicted, this may well provide opportunities for improving the quality of yarns and fabrics and for reducing production costs. Fibre curvature is related to crimp and therefore the measurement of fibre curvature of raw wool provides an alternative to measuring fibre crimp.

Defining fibre curvature is even more complex than defining fibre fineness. This is because curvature exists in 3 dimensions (see Figure 5). Fibre fineness should also be considered in 3 dimensions but the Wool Industry has simplified the problem by creating a one-dimensional definition of fibre fineness, based on the mean transverse dimension of the fibre. In the case of curvature defining the curvature in two dimensions makes a similar simplification.

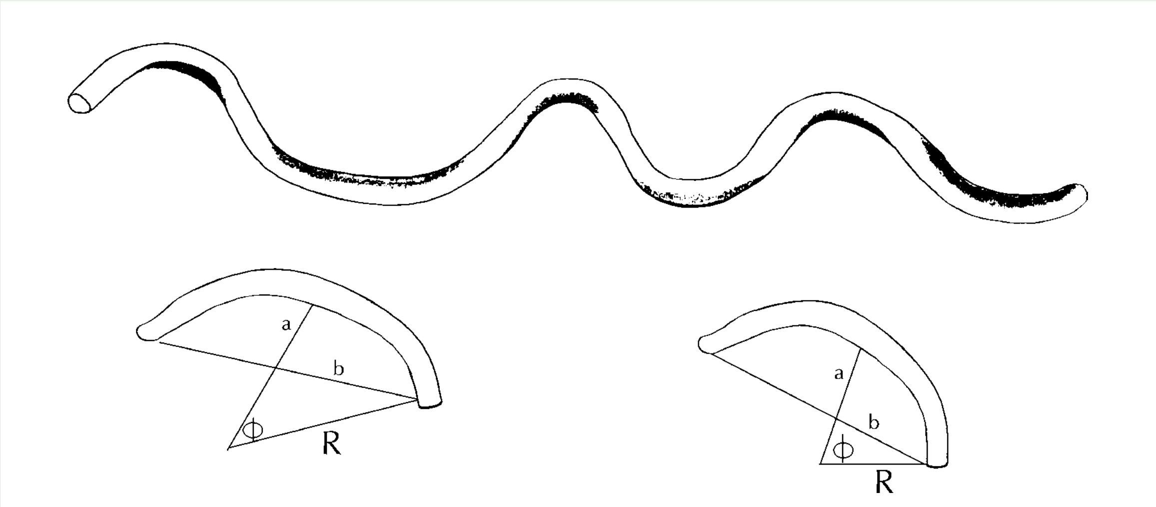
Figure 5 provides a generalised view of the curvature of a merino wool fibre. The fibre bends (curves) and twists (torsion) along its length. In general, the curvature of wool fibres is predominantly in one plane.

Figure 5 : Defining Curvature



There are exceptions, which appear to be related to the density of the wool staple. The studies that are available are not extensive, but nevertheless they tend to support the view that the measurement of fibre curvature in the predominant plane will provide a reasonable quantitative estimate of this particular characteristic. Provided a sufficiently short length of fibre is measured, the definition of fibre curvature is effectively reduced to a two-dimensional problem (see Figure 6). Defining fibre curvature in terms of the arc of a two-dimensional projected image of a short snippet provides scope for the use of conventional microscope assessments of curvature. Certainly there are practical difficulties in doing this, and these are very similar to microscope assessments of fibre fineness. The measurement is very tedious, and to obtain a reasonable estimate a large number of individual measurements are required.

Figure 6 : The Geometry of Curvature

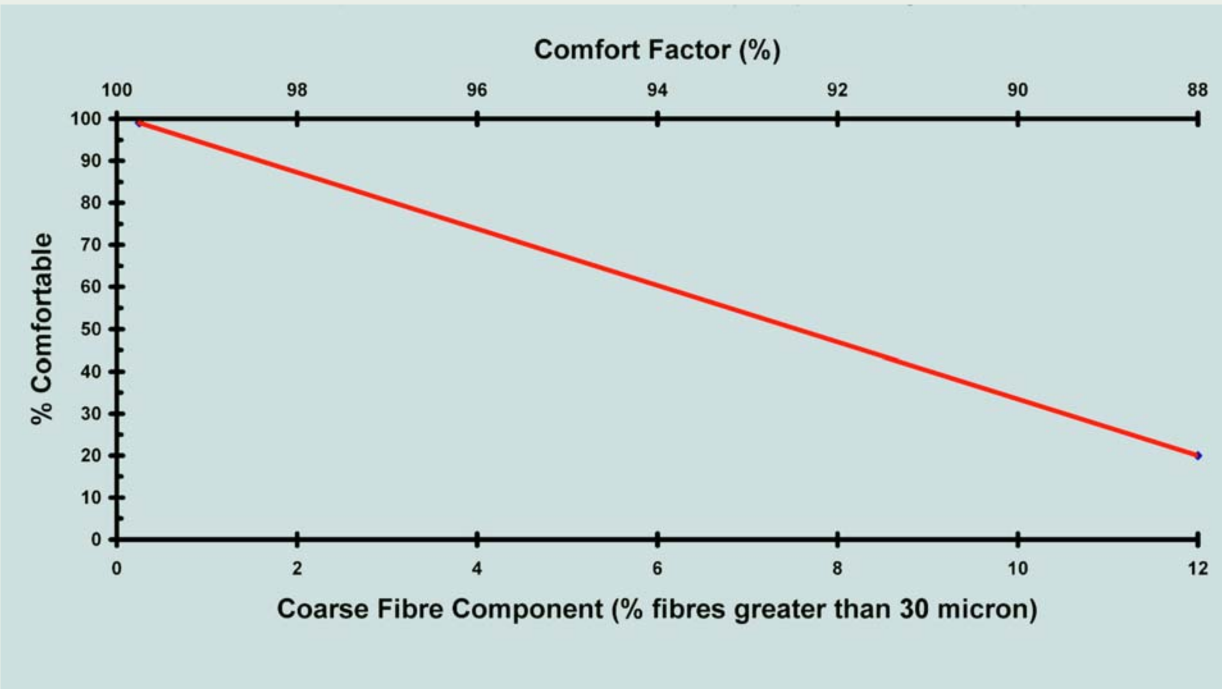


Because it is a more complex geometrical property of wool fibres than fineness, the range of options for defining curvature is considerably less, and indeed by reducing the definition to the radius of a two dimensional arc, as shown above, a compromise is being made. Fibre curvature is not uniform along the length of the fibre and there is variation between fibres as well. The measurement methodology needs to take account of this variation.

The most practical way to do this is to examine individual segments of the fibres and determine the curvature on each segment. Repeated measurements will build up a distribution of curvature from which the average can be calculated. Measurement of small segments allows the measurement to be reduced to two-dimensions. This simplification will introduce an error in the curvature measurement but this is quite small, usually < 10%. The radius of curvature can then be defined as the radius of the arc represented by the two dimensional projection of the fibre snippet. This is indicated in the above diagram by ***R*** and it can be shown, using simple geometry, that $R=2a/(a^2+b^2)$ where ***R*** is the radius of the arc of the fibre, ***a*** is the height of the arc and ***b*** is half the breadth of the arc. However, ***R*** decreases as the curvature increases, so for convenience the curvature is defined as $C=1/R$. Curvature decreases as the arc approaches a straight line. The unit of this measure is degrees/mm.

The mean fibre curvature has been the subject of published research, and some commercial value has been demonstrated. However the distribution of fibre curvature is far from being symmetrical. Therefore distribution characteristics such as Standard Deviation of Fibre Curvature have little meaning, and should not be considered at this stage.

Figure 7 : Comfort Factor & Fibre Diameter



Comfort Factor

CSIRO researchers, sponsored by The Woolmark Company and the Australian Government have unraveled the mystery of why some wool garments are comfortable next to the skin and others are not. Basically the cause is a mechanical effect, resulting from fibre ends sticking out from the fabric and irritating nerve cells in the wearer's skin. If these ends are from coarse fibres they are more rigid and therefore feel more "prickly". Ends from finer fibres are less rigid and bend more easily, and therefore feel less "prickly". The comfort of wool garments produced from the same wool can also be improved (or degraded) by the way the yarn and fabric is manufactured.

The easiest way to produce comfortable garments is to use fabric produced from fine wool. Alternatively, presuming that Diameter Distribution data are available, raw wool could be selected to minimise the proportion of coarse fibres present.

Figure 7 shows how children perceived the skin comfort of a typical plain machine knitted sweater made from wool with different proportions of fibres coarser than 30 microns[1]. Children were used for this particular evaluation because they have more sensitive skins than adults. It must be noted therefore that this illustration should not be applied universally to all situations.

The lower horizontal scale is an index of the coarse fibre content (i.e. the percentage of fibres greater than 30 microns). The vertical scale represents degrees of comfort expressed as a percentage. A figure of 100% on this scale represents no irritation and as this decreases the irritation increases. The upper horizontal scale shows the percentage of fibres less than 30 microns. This is generally referred to as the Comfort Factor.

Determining the Comfort Factor requires measuring the Fibre Diameter Distribution.

[1] Courtesy of Dr Geoff Naylor, CSIRO, Geelong, Victoria, Australia

Measurements provided by the Instrument

Measuring Mean Fibre Diameter by Projection Microscope is quite laborious. A large number of operators and a large number of laboratories must measure a large number of snippets in order to obtain a precise result. Clearly, for routine measurements this is impracticable, and rapid instrumental techniques are preferred.

Instruments such as Airflow, LASERSCAN and OFDA fulfill this need. They provide more precise results much more rapidly. However, none of these instruments can measure fibre fineness directly. Each instrument produces a measurable output signal which is related to fibre fineness, but which can only be converted to a numerical value by referring the magnitude of these signals to the magnitudes of signals obtained from samples of wool for which the Mean Fibre Diameter is already known. Consequently all these instruments must first be calibrated, using wool tops measured by Projection Microscope.

LASERSCAN measures fibre snippets to obtain:

* Mean Fibre Diameter (microns),
* Coefficient of Variation of Diameter (%), and
* the Diameter Distribution Histogram (% of fibres in 1-micron class intervals).

From the Diameter Distribution Histogram coarse edge statistics such as Comfort Factor can also be calculated and reported. The instrument also provides a measurement of Fibre Curvature (degrees/millimetre), but this measurement cannot be certified at this stage because an IWTO Specification for this parameter is not yet available.

Importantly, in terms of the values of the measurements it provides the LASERSCAN closely emulates the Projection Microscope. By measuring single snippets once it also ensures a length weighted distribution is obtained.

Principle of Operation

The illustration (Figure 8) shows how a LASERSCAN works. Fibre snippets are dispersed into isopropanol-water mixture and the resultant suspension then flows through a measurement cell. As they pass through the cell the fibre snippets intersect a thin beam of light generated by a laser. This beam is directed at a measurement detector. The detector produces an electrical signal that is proportional to the amount of light incident upon it. Therefore, when a fibre snippet passes through the beam this electrical signal is reduced by an amount that is directly proportional to the projected area and therefore thickness or diameter of the fibre. The relationship between the magnitude of this decrease and Mean Fibre Diameter is determined by calibrating the instrument using wool tops where the Mean Fibre Diameter and Diameter Distribution have already been determined by direct measurement using the Projection Microscope.

Figure 8 : Laserscan Schematic Diagram

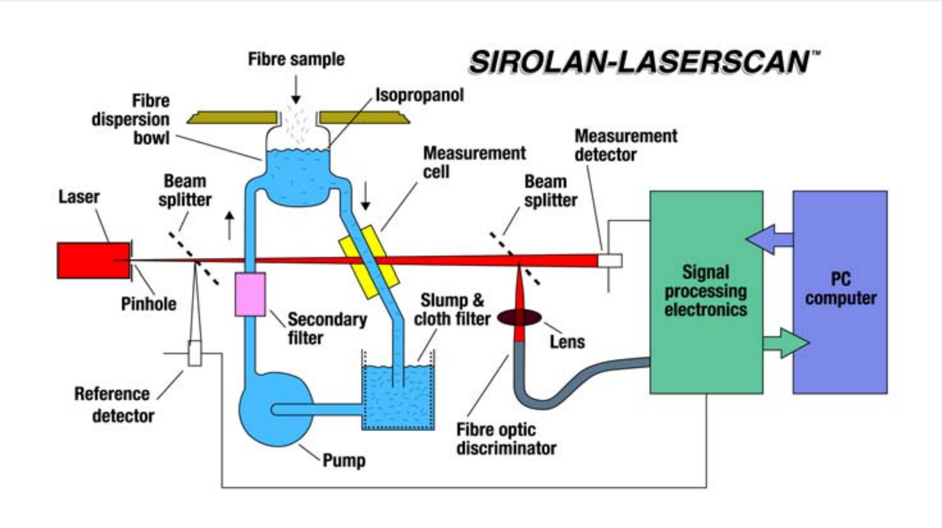
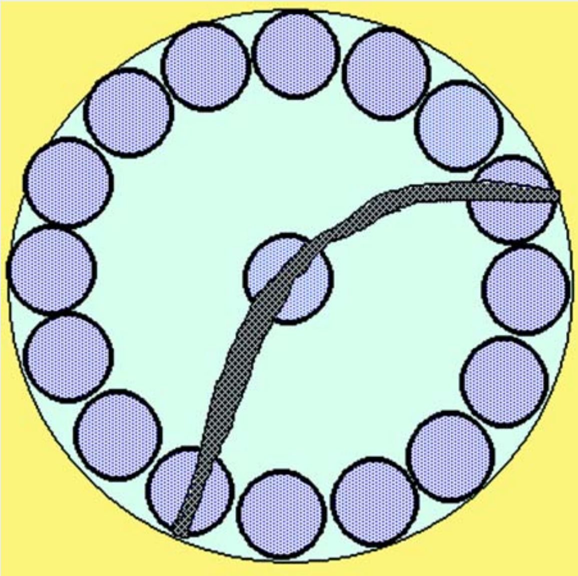


Figure 9 : Optical Discriminator



The LASERSCAN's optical discriminator is fundamentally designed for selecting snippets for the determination of fibre fineness. It consists of a central detector surrounded by 16 smaller detectors. The instrument will only accept a snippet for measurement if the snippet intersects the central detector and two of the surrounding detectors.

However, because the physical dimensions of the detector array is precisely known, the instrument can also differentiate the curvature of the individual fibre snippets, depending upon which pair of the surrounding detectors is intersected by the fibre. The value of ***a*** and ***b*** for each corresponding pair may be inferred from the physical dimensions of the discriminator.

However, it is important that only snippets that fully intersect the beam are actually measured. It is also important that only one snippet is measured at any instant. Otherwise, the signal from the detector will indicate the snippet is either finer or coarser than it really is.

To ensure that only single snippets are measured and that the snippets fully intersect the beam the instrument uses a fibre optic discriminator. The principle of this device is illustrated in Figure 9. It consists of a ring of fibre optic detectors surrounding a single fibre optic detector. The signal from each of these is continuously monitored. A high-speed computer program identifies when a decrease in signal from the central detector and two of the surrounding detectors occurs simultaneously and matches this event with the signal from the main detector. Events that do not match this selection criterion are rejected. The fibre optic discriminator also provides the instrument with the capability to measure curvature (see Figure 9).

In this regard, the LASERSCAN emulates the Projection Microscope, in that only measurements on individual snippets are used to accumulate the Fibre Diameter Distribution. This is critically important in eliminating bias resulting from selective sampling from the total population of snippets presented to the instrument. The LASERSCAN is the only commercial instrument that has this capacity.

Precision

In an ideal world repeated measurement of the same sample will always provide exactly the same result. In a real world this is not so. There is variation associated with every measurement, arising from the measuring instrument, the sample preparation and the sampling itself. There is also human variation but one of the advantages of well-designed instrumental techniques is that the magnitude of human variation is generally significantly reduced.

The precision of a measurement is an indicator of the magnitude of the measurement variation. It is usually defined as a range between which 95% of all repeated measurements will generally lie. The Test Specifications developed by IWTO for the measurement of wool sliver show that the LASERSCAN provides superior measurement precision when compared to any of the other methods. The precision limits for all these specifications, for wool sliver, are summarised in Table 2.

Table 2 : Precision of Fibre Diameter

Instrument	Precision (95% Confidence Level)	
	20 microns	35 microns
Projection Microscope	± 0.60	± 1.40
Airflow*	± 0.41	± 0.55
OFDA	± 0.30	± 0.66
LASERSCAN	**± 0.25**	**± 0.64**

*** Based on <26 micron and >26 micron respectively**

The reproducibility of measurements between laboratories is of major commercial importance to producers, traders and processors. An analysis of the Interwoollabs International Inter-laboratory Round Trials has shown that for wool sliver the LASERSCAN provides superior performance to all other measurements.

As indicated above, the range between laboratories in these trials is best (i.e. lowest) for those laboratories using the LASERSCAN instrument to measure Mean Fibre Diameter.

Comparison with Airflow

The Airflow instrument has been the basis for trading Australian wool for over 25 years. Combing mills have developed relationships between the Mean Fibre Diameter of the raw wool they purchase and the Mean Fibre Diameter of the top they produce from this raw wool. The reliability of these relationships is critical in accurately predicting the quality of the top, yarn and fabrics produced from this raw wool.

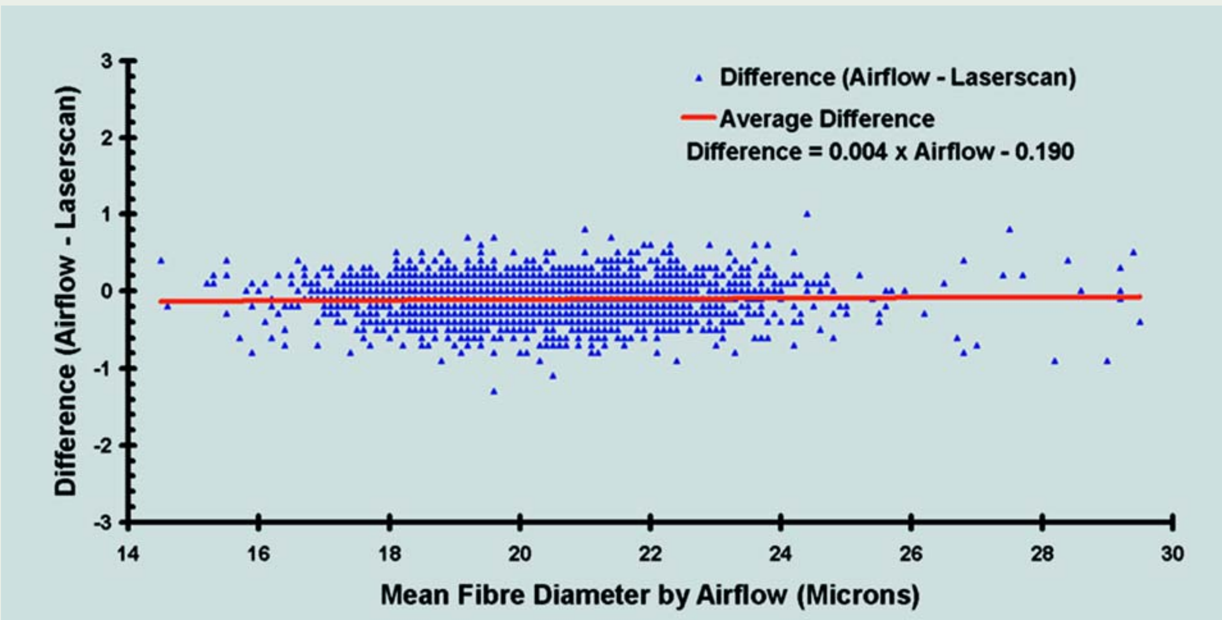
As shown in Figure 10, the Mean Fibre Diameter determined by LASERSCAN and the Mean Fibre Diameter determined by Airflow is, on average, virtually the same.

In this illustration, the difference in Mean Fibre Diameter between Airflow and LASERSCAN for approximately 2500 samples of Australian greasy wool is plotted against the Airflow Mean Fibre Diameter. The solid red line represents the average difference. Note that it is virtually horizontal and very close to zero, indicating that on average there is no difference between the two instruments.

For individual samples there are seemingly large differences. However, 95% of the differences are in the range ±0.5 microns. Given the range of diameters involved this is very close to the expected precision limits for greasy wool for both instruments.

Nevertheless, some of these differences for individual samples may also be real. Unlike the Airflow instrument, the LASERSCAN is not affected by medullation and provides a more accurate measurement of the MFD of medullated wool than the Airflow. LASERSCAN is not affected by Coefficient of Variation of Diameter. It is measuring the individual fibre snippets.

Figure 10 : Difference between LASERSCAN and AIRFLOW



The Airflow is affected by Coefficient of Variation of Diameter. It actually responds to the surface area of a mass of fibres (finer fibres have a larger surface area per unit mass). Two samples may have the same Mean Fibre Diameter but very different Coefficients of Variation of Diameter. In this instance the sample with the higher Coefficient of Variation of Diameter will have a lower surface area, and consequently the Airflow will actually provide a slightly coarser result for Mean Fibre Diameter (MFD) than the real value.

It is also known that for very fine wools (less than 16 microns) the LASERSCAN will provide a finer result than the Airflow. However, it has been demonstrated that this is due to errors in extrapolating the calibration of the Airflow and that the LASERSCAN, for these wools, is probably closer to the true result.

Of the two commercial instruments available for determination of MFD and Distribution in Diameter, for Australian greasy wool LASERSCAN is more highly correlated with Airflow, and shows no apparent bias over the range of diameters normally encountered. Commercially this is very important, as it means that the performance of Australian greasy wool, in almost all instances, can continue to be reliably predicted.

Extensive Research by CSIRO and AWTA Ltd has shown that LASERSCAN is not significantly biased by:

- **Medullation**
- **Curvature**
- **Variations in Diameter Distribution**
- **Fibre ellipticity**
- **Fibre Colour**

Unlike alternative instruments (e.g. OFDA) the calibration of the LASERSCAN is not affected by the mode of preparation of the calibration tops. Hence only one calibration is required for greasy wool, scoured wool and wool sliver.

The LASERSCAN closely emulates the Projection Microscope in that snippets are measured only once thus ensuring a length weighted mean is obtained.

For the i^{th} lot in a consignment, where $i = 1,2,3....q$ and q is the total number of lots

B_i = Wool Base%
M_i = Nett Mass of the greasy wool (kilograms)
D_i = Mean Fibre Diameter (microns)
C_i = Fractional Coefficient of Variation of Diameter
S_i = Estimated Standard Deviation of Diameter

$$C_i = \frac{S_i}{D_i}$$

$$D = \frac{\sum_{i=1}^{q}\left(\frac{M_i B_i}{D_i\left(1+C_i^2\right)}\right)}{\sum_{i=1}^{q}\left(\frac{M_i B_i}{D_i^2\left(1+C_i^2\right)}\right)}$$

$$C = \left[\frac{\sum_{i=1}^{q} M_i B_i}{D^2 \sum_{i=1}^{q}\left(\frac{M_i B_i}{D_i^2\left(1+C_i^2\right)}\right)} - 1\right]^{\frac{1}{2}}$$

where D is the Mean Fibre Diameter and C is the Fractional Coefficient of Diameter of the consignment.

Processing Predictions

The availability of CVD information on Australian greasy wool will provide more accurate prediction of the MFD of wool tops; particularly those produced from consignments where the component lots have unusually low or high CVD's. The CVD information opens up the possibility of extending the range of MFD for the component lots within a consignment, yet still allowing accurate prediction of combing performance.

To understand this, it is necessary to understand how an average MFD for a combing consignment is calculated. For non-mathematicians the calculation is quite complex but greatly simplified in the modern world by the availability of computers. The mathematical equations involved are shown on the left.

When Airflow became the primary method for calculating the MFD of a delivery, it was not possible to use these equations because this instrument did not provide the CVD information. An approximation was made which assumed that the range in MFD and CVD between the component lots was small.

If these assumptions are correct then the prediction of the MFD of a wool top will generally be quite reliable and this has indeed been the case for many years. It is well known that if the average MFD of the wool top is usually about 0.2 to 0.3 microns coarser than the average for the greasy wool (measured by Airflow) from which it was produced.

Of course there are processing effects. During processing some fibre is removed and generally this wastage is finer than the average for the greasy wool. The extent to which this occurs can be controlled by the mill, but it cannot be eliminated. This is why tops are generally slightly coarser.

However, occasionally, and without apparent reason, the actual differences are much larger than expected. There are many reasons why this may occur, among which is the effect of CVD on the measurement of MFD by Airflow.

Why is this the case? It is known that the Airflow is affected by the CVD of the sample it is measuring. Generally, the magnitude of this effect is small, smaller than the confidence limits of the method. However, the effect increases as the CVD for a given MFD becomes substantially greater than or substantially less than the CVD of the tops used to calibrate the Airflow instrument at the particular MFD. For abnormally high values of CVD, the Airflow estimates of MFD will tend to be higher than the estimates on the same sample obtained by LASERSCAN (and Projection Microscope). For abnormally low values of CVD the Airflow estimates will tend to be lower.

The commercial implications of this are simply stated. The CVD of a sliver produced from a wool blend is determined by two factors:

* the CVD of each of the sub-lots in the consignment used to produce the sliver; and
* the range in MFD between sub-lots in this consignment.

The first factor becomes the more important in special circumstances. Consignments assembled from lots that have a lower than normal CVD, and where the range in MFD between lots is very small, are more likely to have an abnormally low CVD. This situation is most likely to occur in fine wool consignments, particularly where the lots have been classed using objective MFD data for each fleece, or it may occur where the consignment consists of lots assembled from an individual farm. It will result in the MFD of the sliver, measured by Airflow, being finer than measurements made by LASERSCAN (or Projection Microscope).

If it is assumed that the range in Mean Fibre Diameter and Fractional Coefficient of Variation of Diameter between component lots of a consignment is small then the equation for calculating the Mean Fibre Diameter of the consignment is greatly simplified.

$$D = \frac{MB}{\sum_{i=1}^{q}\left(\frac{M_i B_i}{D_i}\right)}$$

Here ***B*** is the Wool Base (%) and ***M*** is the nett mass (kilograms) of greasy wool for the consignment.
If these assumptions are not correct, then the accuracy of the prediction of combing performance will be reduced. Ensuring that the range in Mean Fibre diameter is small is a simple exercise because the component lot details are known. However, prior to the introduction of LASERSCAN this was not possible for Coefficient of Variation of Diameter. Variation in Coefficient of Variation of Diameter can cause errors in predicting the diameter of the top.

For consignments assembled from visually classed farm lots or dealer lots, the second of these factors is likely to be the more important. The larger the range in MFD between the sub-lots the larger the CVD of the consignment. The MFD of the sliver produced from these consignments when measured by Airflow is likely to be higher than the measurements made by LASERSCAN (and Projection Microscope). Conversely the narrower the range in MFD between the sub-lots the smaller the CVD of the consignment, and the Airflow MFD is likely to be closer to the MFD obtained by LASERCAN (and Projection Microscope).

It must also be noted that situations may arise where these factors can act together to either increase the differences or to reduce the differences between the methods.

The relationship between the calculated diameter, derived from measurements on core samples from the consignment sub-lots, and the diameter measured on the resulting wool top is well understood in most mills.

These comparisons (core/comb) have been derived using Airflow technology. Uncertainty in the relationship may be reduced when the CVD information for the greasy wool is available.

Table 3 shows the magnitude of the errors in MFD measured by Airflow that could be expected for differing Standard Deviation (SD) values. The corresponding CVD is shown in brackets.

In the case of the 20.0 micron wool (measured by LASERSCAN) the error in the Airflow measurement arising from the effect of CVD will be near zero (-0.1 microns) at a SD of 4.0 microns (i.e. CVD 20%). One would expect a bias of -0.4 microns when the SD was 3.0 microns (i.e. CVD 15%) and a bias of +0.4 microns when the SD was 5.0 microns (i.e. CVD 25%). It must be emphasised that these differences only relate to effects from differing SD or CVD.

The magnitudes of the potential errors are small, but they can be commercially significant. The commercial risk, in most instances will be minimised by the availability of data produced by the LASERSCAN instrument, and the more accurate calculation of consignment MFD using the correct formula incorporating the CVD value.

Table 3

Sample SD by LASERSCAN (microns)	Sample MFD by LASERSCAN (MICRONS)				
	19.0	20.0	21.0	22.0	
2.5	18.5 (13)				Airflow is finer
3.0	18.7 (16)	19.6 (15)	20.5 (14)		Airflow is finer
3.5	18.9 (18)	19.7 (18)	20.6 (17)	21.5 (17)	Airflow is finer
4.0	19.0 (21)	19.9 (20)	20.8 (19)	21.7 (18)	Airflow is finer
4.5	19.3 (24)	20.1 (23)	21.0 (21)	21.9 (21)	Airflow is finer
5.0	19.5 (26)	20.4 (25)	21.2 (24)	22.1 (23)	Airflow is coarser
5.5		20.6 (28)	21.5 (26)	22.3 (25)	Airflow is coarser
6.0				22.6 (27)	Airflow is coarser

BENEFITS TO WOOLGROWERS AND WOOL PROCESSORS

The major benefit to woolgrowers and wool processors is in the additional information that LASERSCAN will provide - namely Coefficient of Variation of Diameter, Comfort Factor and Fibre Curvature.

Mean Fibre Diameter, Coefficient of Variation of Diameter and Fibre Curvature all affect the quality of tops, yarns and fabrics. Australia will be the only wool producing country where these parameters will be available on all sale lots. This will provide real differentiation of Australian wool from competing wool producing countries. Already many woolgrowers are seeking to improve the quality of the wool they produce by reducing the Coefficient of Variation of Diameter of their flocks. However, without presale measurements being readily available there has been no immediate benefit or premium available for doing this.

Past experience has always been premiums develop when a characteristic is objectively measured and when wool buyers and processors are able to select wools on the basis of this characteristic.

LASERSCAN will also provide more accurate estimates of the Mean Fibre Diameter of farm lots than has been previously possible. Combined with the Coefficient of Variation of Diameter this will enable more reliable prediction of the Mean Fibre Diameter and Coefficient of Variation of the top. The additional information will also provide an opportunity to refine the specification of greasy wool, utilising Coefficient of Variation, to spread purchases of farm lots above and below the required Mean Fibre Diameter, thereby reducing the step decreases in price that currently occur, sometimes for a 0.1 micron difference.

GLOSSARY OF TERMS

Accuracy

A measure of the closeness of a test result to the true value. The true value of a measured quantity can only be determined by measurement systems that are calibrated by direct reference to primary references such as length, weight, force etc.

Airflow

A method of measuring the mean fibre diameter of a sample of wool in which a test specimen (a measured mass of the scoured, dried and carded sample or a measured mass of sliver), after exposure to a conditioning atmosphere, is compressed to a fixed volume and a current of air is passed through it. The rate of flow is then adjusted so that the pressure drop across the sample equals a predetermined value, or the pressure drop across the sample is adjusted until the air flow equals a predetermined value. The rate of flow in the first case, or the pressure difference in the second case, is an indicator of the mean fibre diameter of the wool in the sample.

Bias

A constant or systematic difference between a true value and corresponding test results. (Also see: *Accuracy* and *Precision*.)

Class Interval

The classes into which the individual snippet fibre diameter measurements are grouped, where the micrometre range of each group is identical, the micrometre value of each interval is an integer, and the micrometre value of the mid-point of each class interval is also an integer.

Coarse Fibre Content

The percentage of fibres in a Fibre Diameter Distribution which are coarser than 30 micrometres. (Also see: *Comfort Factor*.)

Coefficient of Variation

A statistical measure of the variability exhibited within a set of values. It expresses the standard deviation as a percentage of the mean; the higher the CV, the greater the variability.

The coefficient of variation of a sample may be calculated from:

$$CV = 100 \times \frac{S}{\overline{X}} \quad (\%)$$

where CV = coefficient of variation

S = standard deviation of the sample

$\overline{X}$ = mean of the sample

Coefficient of variation is often measured for fibre diameter, staple length and fibre length in sliver. (Also see: *Fractional Coefficient of Variation*.)

Comfort Factor

The percentage of fibres in a Fibre Diameter Distribution which are finer than 30 micrometres. (Also see: *Coarse Fibre Content*.)

Conditioning

A process whereby wool fibres are exposed to a conditioning atmosphere until the moisture absorbed by the fibres attains equilibrium.

Conditioning Atmosphere

A volume of air, capable of being maintained at standard temperature or humidity, or both, in which specimens are conditioned in a standard atmosphere. For wool testing this is usually a temperature of 20±2^{o}C and a relative humidity of 65±3%. (Also see: *Conditioning*.)

Confidence Limits

An expression of the precision of the mean of a set of values, usually associated with a stated probability, most often 95%. It is the interval around the mean within which, with the stated probability, the true value is expected to lie.

Coring Tube

A tube of circular cross-section which is equipped with a sharpened, replaceable tip. The tip enables the tube to penetrate a bale of raw wool without rotation, remove a cylindrically shaped portion of the wool and retain it without change in material or moisture content.

Very small diameter coring tubes may also be used to obtain fibre snippets for fibre diameter testing. (Also see: *Minicore*.)

Cover slip

A very thin square section of glass placed over a specimen of snippets distributed over a glass slide, for measurement by Projection Microscope. (Also see: *Mounting Fluid.*)

Crimp

The waviness of a fibre, expressed numerically as the number of complete waves per unit length; crimp is usually taken as an indicator of mean fibre diameter, the higher the number of crimps per unit length the finer the wool.

Crimp Definition

The degree of alignment of the crimp waves within a staple.

Crimp Frequency

The number of *crimp* waves per centimetre of *staple length. Coefficient of variation* of crimp frequency refers to the variation in frequency between *staples* within a *lot.*

Curvature

The inverse of the radius of arc of a segment of a fibre *snippet.* Curvature is expressed as degrees/mm.

CVD

See *Coefficient of Variation of Diameter.*

Distribution Histogram

See *Fibre Diameter Distribution.*

Ellipticity

A term used to describe the shape of the cross-section of a wool fibre. It is quantified by assuming the cross section is an ellipse and calculating the ratio of the major axis to the minor axis. Circular cross-sections therefore have an ellipticity of 1.

Fibre Diameter Distribution

The distribution of *fibre diameter* in a wool sample. Distribution can be expressed in the form of a frequency table or as a frequency histogram with data grouped into *class intervals* of one micrometre size, and integer micrometre values as midpoints of the class intervals.

The results may be expressed in a number of ways including *standard deviation, coefficient of variation* and the percentage of fibres coarser than a given value such as 30 microns.

Fibre Fineness

Used interchangeably with *Mean Fibre Diameter.* The term "Mean Fibre Diameter" in the context of wool fibres can be misleading, since it implies that wool fibres have a circular cross section. In describing the thickness or thinness of wool fibres it is more exact to use the term "fibre fineness". The word "fineness" does not imply any particular geometry for the shape of the cross section.

Fibre Optic Discriminator

A component of a LASERSCAN instrument used to ensure that the instrument only measures fibres that adequately intersect the *laser beam.* It consists of a circular array of 16 optical fibres surrounding a central optical fibre. Signals generated by the Optical Discriminator are also used to determine fibre *curvature.*

Fractional Coefficient of Variation

A statistical measure of the variability exhibited within a set of values. It expresses the *standard deviation* as a fraction of the *mean.* The fractional coefficient of variation of a sample may be calculated from:

$$FCV = \frac{S}{\overline{X}}$$

where FCV = fractional coefficient of variation

S = standard deviation of the sample

$\overline{X}$ = mean of the sample

(Also see: *Coefficient of Variation*).

Frequency Distribution

See *Fibre Diameter Distribution.*

Glass Slide

A rectangular section of clear glass, upon which *snippets* are dispersed for measurement by *Projection Microscope.* (Also see: *Mounting Fluid.*)

International Wool Textile Organisation

A international forum for establishing standardised test procedures (IWTO Test Specifications), regulations governing the use of these procedures (IWTO Regulations), and procedures for arbitrating disputes over commercial transactions involving raw wool, wool sliver and wool yarns (the IWTO Blue Book). IWTO is pivotal in providing a technical and commercial framework for international and intranational trade involving wool.

Representation within IWTO is via National Committees appointed by the Wool Industry associations within member countries.

Isopropanol

Isopropyl alcohol is a three-carbon molecule within the family of chemicals defined as alcohols. It has the chemical formula $CH_3CHOHCH_3$. It is a clear liquid and is used as the fluid medium for dispersing *snippets* for measurement by the *LASERSCAN* instrument.

IWTO

See *International Wool Textile Organisation*

Laser

A device for producing a narrow intense parallel beam of light, with a specific wavelength.

Laser Beam

The light produced by a *laser*.

LASERSCAN

An instrument to measure *mean fibre diameter* and *fibre diameter distribution* by detection of shadows in a *laser beam,* brought about by causing snippets to be carried through the beam in a suitable liquid.

Lot

Any number of *bales* of wool, of similar mass and dimensions, prepared for sale as a single parcel in accordance with accepted trade practices.

Mean

Arithmetic average; the mean of a set of values is calculated by dividing the sum of those values by the number of them. (For example, *see Mean Fibre Diameter.*)

The mean of a sample may be calculated from:

$$\overline{X} = \frac{\sum X_i}{N}$$

where $\overline{X}$ = mean

X_i = the *ith* measurement made on the sample

N = is the number of items measured in the sample

Mean Fibre Diameter

The average thickness of a sample of fibres in *micrometres*. For wool, because individual fibres have different lengths, the mean diameter is weighted for the length. (Also see: *Fibre Diameter Distribution, Fineness and Micron.*)

Medullation

The degree to which the centre of a wool fibre (the medulla) is hollow. Medullation is quantified in terms of the number of such fibres observed within a sample of fibres.

MFD

See *Mean Fibre Diameter*

Micrometre

A unit of length measurement equal to one-millionth of a metre; it is the unit of measurement for the *fibre diameter* of wool. It is commonly called a *micron*.

The symbol ‘µm’ is used for micrometre.

Micron

Commonly used name for the unit of measurement of *fibre diameter*, correctly termed a *micrometre* (µm).

Microtome

A mechanical guillotine consisting of two parallel, very thin sharp blades separated by a distance of 0.8 to 2.0 mm. The microtome is used to cut through a sample of *wool top* or *wool sliver* to obtain a sample of fibre *snippets*.

Minicore

A *subsample* obtained by small-diameter *coring tubes* to provide a representative *snippet* sample of sufficient mass.

Mounting Fluid

A clear fluid within which fibre *snippets* are dispersed prior to measurement by *Projection Microscope*.

The mounting fluid is spread on a *glass slide* and covered with a *cover slip* so as to ensure no air bubbles are retained within the fluid and the snippets are evenly dispersed throughout the fluid.

OFDA

See *Optical Fibre Distribution Analyser*

Optical Fibre Distribution Analyser

An instrument for measuring *fibre diameter mean and distribution* using an automated microscope and image analysis techniques. (Also referred to as *OFDA*.)

Precision

An indicator of the repeatability of a measurement; it is often expressed in terms of *confidence limits*. (Also see: *Accuracy*.)

Projection Microscope

An instrument for measuring *fibre diameter mean and distribution*. Magnified images of the profiles of short lengths (*snippets*) of fibre are projected on a screen and their widths measured by using a graduated scale.

Raw Wool

Greasy wool; wool which has been scoured, carbonised, washed or solvent degreased; scoured skin wools; washed skin wools; and slipe wools. It consists of wool fibre together with variable amounts of impurities.

SD

See *Standard Deviation.*

Sliver

See *Wool Sliver*

Snippet

Very short pieces of fibre, typically around 0.8 to 2 mm long, which have been cut to measure fibre diameter and related properties. (Also see: *Minicore, Microtome, Laserscan, OFDA and Projection Microscope*.)

Standard Deviation

A measure of dispersion of individual results. Standard deviation is expressed in the units of measurement. (Also see: *Variance* and *Coefficient of Variation*.)

Staple

A well-defined bundle of fibres which has been removed from a mass of *greasy wool* as a unit.

Staple length

The length of a *staple* projected along its axis obtained by measuring the staple without stretching or disturbing the *crimp* of the fibres.

Top

See *Wool Top* or *Wool Sliver*

True Value

The absolute value of a characteristic; it is almost always unknown. Measurements of the characteristic are, in the absence of *bias*, normally distributed about the *true value* with a *variance* that is also unknown in a particular case.

The *mean* of a set of measurements is the best estimate of the true value. (Also see: *Accuracy*.)

Variance

The variance of a sample is the square of the *standard deviation* and is a measure of the distribution of values around the mean. It is expressed in the units of measurement squared. (Also see: *Coefficient of Variation*.)

The variance of a sample may be calculated from:

$$S^2 = \frac{\sum \left(X_i - \overline{X}\right)^2}{N-1}$$

where S^2 = variance (standard deviation squared)

X_i = the ith value measured in the sample

$\overline{X}$ = mean of the sample measurements

N = the number of items measured in the sample

Wool Base

The oven-dry mass of wool fibre free from all impurities, expressed as a percentage of the mass of the sample.

Wool Sliver

A continuous strand of loosely assembled wool fibres which may contain variable amounts of *vegetable matter* and is approximately uniform in cross-sectional area and with none or very low levels of twist. This includes carded sliver, combed sliver, gilled sliver, *top* and roving.

Wool Top

Sliver that forms part of the starting material for the worsted and certain other drawing systems, usually obtained by the process of *combing*, and characterised by the following properties:

(a) A substantially parallel formation of the fibres, essentially free of vegetable matter.

(b) The absence of fibres so short as to be uncontrolled in the preferred system of drawing.

(c) A substantially homogeneous distribution throughout the sliver of fibres from each length group present.

BIBLIOGRAPHY

L.J. Lynch & N. Thomas, Text. Res. J., **41**(7), 568-572, 1971, *Optical Diffraction Properties of Single Fibres*

L.J. Lynch & N.A. Michie, Text. Res. J., **46**(9), 653-660, 1976, *An Instrument for the Rapid Automatic Measurement of Fiber Fineness Distribution*

K. Baird & R.G. Barry, Technical Committee, IWTO, Report No. 5, Nice, December 1992, *Evaluation of the Sirolan Laserscan Instrument. Part 1. Test Specimen Preparation Factors that Influence the Measured Mean Fibre Diameter*

K. Baird & R.G. Barry, Technical Committee, IWTO, Report No. 6, Nice, December 1992, *Evaluation of the Sirolan Laserscan Instrument. Part 2. Accuracy and Precision of the Measure*

T. Dabbs & M. Glass, Technical Committee, IWTO, Report No. 11, Punta del Este, April, 1992, *Discrimination in the Wool Fibre Diameter Analyser*

T. Dabbs & M. Glass, Technical Committee, IWTO, Report No. 13, Punta del Este, April, 1992, *The Physics at work in the Wool Fibre Diameter Analyser*

P.A. Irvine, M.R. Bow & H.F. Van Schie, Technical Committee, IWTO, Report No. 11, Nice, December, 1992*, Calibration of Sirolan-Laserscan with Interwoollabs Standard Tops*

K. Baird & R.G. Barry, Technical Committee , IWTO, Report No. 19, Istanbul, May, 1993, *Measurement of Mean Fibre Diameter Using SIROLAN LASERSCAN: Results of an International Round Trial*

M.W. Bow, H.F. Van Schie & P.A. Irvine, Technical Committee, IWTO, Report No. 24, Istanbul, May 1993, *An Evaluation of some aspects of the Sirolan Laserscan*

K. Baird, R.G. Barry & J.W. Marler, Technical Committee, IWTO, Report No. 7, Nice, December 1994, *Comparison of Mean Fibre Diameter Measurements by Airflow and Laserscan for a Wide Range of Wool Types*

T.P. Dabbs, H.F. Van Schie & M. Glass, Technical Committee, IWTO, Report No. 2, Nice, December 1994, *The Effect of Fibre Curvature on Laserscan Diameter Measurement*

D. Charlton, Wool Tech. and Sheep Breeding, **43**(3), 212-228, 1995, *Sirolan-Laserscan. A Review of Its Development, Performance and Application*

M. Glass, T. Dabbs & P.W. Chudleigh, Text. Res. J., **65**(2), 85-94, 1995, *The Optics of the Wool Fibre Diameter Analyser*

IWTO Standard Test Method IWT0-12-95, *Measurement of the Mean and Distribution of Fibre Diameter using the Sirolan-Laserscan Fibre Diameter Analyser*

M. Glass, Applied Optics, 35(10), 1605-1616, 1996, *Fresnel diffraction from curved Fiber snippets with application to Fiber diameter measurement*

P.A. Irvine & R.G. Barry, Technology & Standards Committee, IWTO, Report No. 16, Nice 1997, *An Improved Calibration Model for the Sirolan LASERSCAN*

P.J. Sommerville, Technology & Standards Committee, IWTO, Report No. 15, Boston 1997, *Measurement of the Fineness of Superfine Wool: a Comparison of Airflow, LASERSCAN and OFDA*

D.G. Knowles, Technology & Standards Committee, IWTO, Dresden, 1998, *Investigation into Mean Diameter Instrument Differences in the Measurement of New Zealand Superfine Wool,*

D.G. Knowles, P.R. Greatorex and G. V. Barker, Technology & Standards Committee, IWTO, Report No. 12, Dresden, 1998, *Comparison of IWTO Test Methods for Fibre Diameter Measurement of the New Zealand Wool Clip – Part 1: Mean Fibre Diameter*

D.G. Knowles, P.R. Greatorex and G. V. Barker, Technology & Standards Committee, IWTO, Report No. 13, Dresden, 1998*, Comparison of IWTO Test Methods for Fibre Diameter Measurement of the New Zealand Wool Clip – Part 2: Fibre Diameter Variability*

P.J. Sommerville, Technology & Standards Committee, IWTO, Report No. CTF 04, Nice 1998, *Measurement of the Fineness of Superfine Wool: Effect of the revised LASERSCAN Calibration Function on comparisons between Airflow, LASERSCAN and OFDA*

J.W. Marler, Technology and Standards Committee, IWTO, Report No. SG 02, Florence, May 1999, *Interwoollabs Report On 1998 Round Tests*

D.G. Knowles & J.W. Marler, Technology and Standards Committee, IWTO, Report No. RWG 03, Florence, May 1999,*The Relationship between Mean Fibre Diameter Measurements by Airflow, Laserscan and OFDA for Australian and New Zealand Wools*

P.J. Sommerville, Technology and Standards Committee, IWTO, Report No. RWG 03, Florence, May 1999*, Introduction of Sirolan Laserscan as the Standard Service for Certification of Mean Fibre Diameter: Part 1 - Commercial and Technical Implications*

P.J. Sommerville, Technology and Standards Committee, IWTO, Report No. RWG 03, Florence, May 1999*, Introduction of Sirolan Laserscan as the Standard Service for Certification of Mean Fibre Diameter: Part 2 - Technical Supplement*

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