IIC-sponsored research

RAPID TESTING OF MATURITY AND FINENESS OF COTTON FIBRES

Brief summary of project to be conducted by Mr. E. Lord, Shirley Institute Manchester.

The work is co-sponsored by the International Institute for Cotton and the Shirley Institute. Contract signed in April 1968.

The object is to develop an air-flow instrument which will test a plug of cotton fibres at two pressures and give a separate reading of maturity and fibre fineness. The idea has first been proposed by Professor Hertel about twenty years ago but his "Arealometer" was not a convenient enough instrument for wide application.

The Micronaire has found general acceptance but its reading is a combined effect of fineness and maturity, the air-flow being approximately proportional to a product of maturity and linear density (millitex). In the U.S.A. where mills use a comparatively small range of cottons with fairly consistent fineness, one knows generally the Micronaire value a cotton "should have" if it is mature; a lower Micronaire reading indicates immaturity and the Micronaire often serves, in effect as a maturity tester. In Europe, a much larger range of cottons is used and the Micronaire reading for a particular cotton, if it is mature, is frequently unknown. Therefore, a separate reading of maturity and fineness is likely to be useful for the mills, for research, and possibly for the cotton trade.

The research work will seek the best conditions of operation at two pressures, and a thorough check will be made of the accuracy of the results. A prototype instrument will then be built with a view to ultimate commercial production. Speed and convenience of operation will be major considerations; ideally the instrument should be suitable for use in the cotton trade and industry. If only a somewhat slower instrument can be built, then its main application will be in research and processing control.

DEVELOPMENT OF RAPID METHOD OF MEASURING COTTON FIBRE MATURITY AND LINEAR DENSITY

by

E. Lord, Shirley Institute, Manchester

Phase I of research project for International Institute for Cotton under project G 68. P 1 of the Shirley Institute.

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Note: This is an "electronic" version of Mr Lord's report. The original report was scanned into *Omnipage Pro*, in May 2006, and edited in *MS Word*. The original had been produced with a manual typewriter and, therefore, a great deal of editing and correction was necessary after the *OCR* process. Although the resulting text has been checked carefully, it is possible that some transcription errors have escaped. All of the tables have been reconstructed. In particular, the data of Table 8 have been entered manually, re-arranged, and exported into *MS Excel* which was used to re-construct Figures 1 and 2. Note that the correlation coefficients given on these graphs are those calculated by *Excel*. They are actually the coefficients of determination (R^2), so the numbers are not the same as those given in the text by Mr Lord, who quotes the square roots (r).

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Summary and Conclusions

This report describes the work undertaken in Phase I of a research project supported by the International Institute for Cotton and carried out at the Shirley Institute, Manchester. The main objective of the work was to study the feasibility of obtaining from measurements of air permeability separate estimates of cotton fibre maturity and fibre linear density that would be unbiased and sufficiently accurate to be of value in assessing the quality of samples representing commercial production of established varieties and in evaluating the potential of new strains grown under experimental conditions and being developed to obtain more satisfactory crops.

Most airflow tests in current use for samples of raw cotton yield quantities such as the Micronaire value that depend upon the joint variation in both fibre maturity and fibre linear density. Interpretation of the physical significance of such results depends upon either past experience of the material under similar circumstances or on having available additional information about one of the two fibre characters concerned. In some less frequently applied tests use has been made of small deviations from the classical physical flow laws to obtain separate estimates of maturity and fineness from air permeability tests at two specimen compressions. However, such tests have not been adopted for widespread application, because of more difficult test techniques, or uncertainties regarding rigid interpretation of the results, or insufficiently high test precision.

In Phase I of this project initial experiments indicated that better estimates of the fibre characters are more likely to be realisable from two permeability measurements both made along the axis of compression of a test specimen rather than when either one or both of such measurements relate to the permeability in a direction perpendicular to the axis of fibre compression.

The major experimental work with flow along the axis of compression and permeability measurement made at two different densities of test specimen has shown that:

1. The dependence of air permeability on fibre maturity and linear density is in accordance with classical flow theory providing that the specimen packing density is low.
2. As the density of packing is increased the effect on the specimen permeability of fibre maturity becomes relatively more pronounced and there is also a small increase in the relative effects of fibre linear density. Because of these differential fibre effects, measurements of air permeability of test specimens compressed in turn to two different packing densities may be used to derive separate estimates of fibre maturity and linear density by fitting suitable statistical equations to the empirical data.
3. The differential effects of the fibre characters in the permeability relations become more pronounced as the ratio of the two specimen packing densities is increased. Over a 10:1 range in densities very low and very high degrees of compression gave the most pronounced levels of the various classes of experimental variation in the permeability measurements.

4. Analysis of data for a large set of cottons covering the world's normal range in fibre maturity and fineness indicate that permeability measurements have the lowest experimental variation and yield the most accurate estimates of these characteristics if the initial low packing density is in the region of 0.2 g/ml and the second and higher density is about 0.4 g/ml.
5. With the above test conditions the accuracy of determination of fibre maturity and linear density is sufficiently high for many practical purposes, for example in exerting an effective selection pressure in cotton breeding and in avoiding immature commercial supplies.
6. The derivation of unbiased estimates of fibre maturity and fineness necessitates the use of somewhat involved mathematical relations which in turn rule out the use of simple instrument scales marked directly in units of the fibre characteristics. In practice, however, the practical evaluation of the mathematical functions could be avoided by using simple transformation nomograms.
7. The accuracy yielded on the simple test equipment used in this investigation warrants continuing with Part II of the project: the construction of a prototype instrument.

It is also recommended that the prototype instrument should

a) Give full consideration to the need for rapid and easy mode of operation and have incorporated in it components with a test performance that have been formulated in the detailed *Conclusions* section at the end of this report.

b) Be given a full trial to evaluate its performance, particularly by assessing statistically any gains in accuracy compared with the performance of the simple experimental apparatus used in this present investigation.

c) Be constructed such that, if approved, it could be manufactured with confidence that subsequent commercial instruments would give an identical performance in both test level and accuracy. Because calibration of the prototype is empirical and based on a wide range of tests on cotton samples the design must be such that eventual manufactured instruments would yield an identical test performance by reliance on construction to adequate engineering specification of essential dimensions and tolerances of features such as specimen holder coupled with requiring a verifiable performance of ancillary components such as check flowmeters, air pressure controllers, etc.

d) The final form of the prototype should be such that the instrument will serve as a 'master' to avoid any lengthy direct calibration procedure based on tests on dozens of cotton samples.

Introduction

Basic studies by various workers of airflow through compressed test specimen plugs of randomly packed cotton indicate that, for a constant density and size of specimen, the rate of airflow Q and pressure differential P along the length of the plug are related to the fibre characteristics by an expression of the form

$$Q/P = a \,.\, M.H = a \,.\, M^2.Hs \qquad (1)$$

in which

> M is the average fibre maturity ratio, a quantity directly proportional to the average degree of area of cell wall thickening.
>
> H is the average fibre linear density.
>
> Hs is the standard fibre weight per centimetre, a quantity proportional to the square of the average fibre perimeter and calculated from the identity $Hs = H/M$.

and the constant a depends upon the specimen mass and dimensions.

Although not fully realised at the time of its initial development, the relation (1) provides a means of interpreting the results of air permeability tests made on cotton using the Micronaire instrument. It also forms the basis of other fundamentally similar instruments. Changes in the ratio Q/P shown by a particular test instrument (usually the pressure P is kept constant and changes in Q are indicated on a scale) reflect changes in fibre maturity alone, changes in intrinsic fibre fineness alone, or simultaneous changes in both M and Hs.

Experience of the test applied to commercial crops of a given seed variety, especially if the crop is from an area without abnormal growth conditions in some parts, indicates that the intrinsic fineness Hs shows fairly small variation, commonly being within the range ± 5%. The variation in the maturity ratio about its average value is usually appreciably larger, often ± 10% and not infrequently more, with M^2 therefore varying by often ± 20% and sometimes more. It follows from relation (1) that, under such conditions the instrument readings registering variations in Q/P provide indications of major differences in fibre maturity subject to the effects of lesser and unknown differences in intrinsic fibre fineness.

An airflow instrument of this nature is less useful in the field of cotton breeding than in its application to assessing individual bales of a commercial crop. In the former field, if selections are made on the basis of increased test values of Q/P to develop a more mature type of cotton, there is brought into operation a further selection pressure in the direction of increased coarseness (and indirectly through genetic relations, of reduced fibre tenacity) of the resultant material. Equally, if selections are made repeatedly on the basis of lower test values of Q/P amongst material judged likely to be of satisfactory fibre maturity, in order to derive a finer type of cotton, there will also be a simultaneous selection pressure favouring a shift in the direction of lower fibre maturity. Both in the commercial field for choosing suitable mill supplies from available bulk amounts and also in cotton breeding for developing new strains of desired and measured fibre quality there is the need to have independent fibre maturity and fibre fineness tests. Established methods such as direct measurement of fibre linear density and estimation of fibre maturity by the caustic soda swelling procedure usually demand too such skill and time when large numbers of samples require testing.

More detailed work by various workers shows that the flow phenomenon is more complex than that indicated by the classical approach to the problem. In particular it has been found that, when the same specimen is tested at two different densities of packing, samples of different fibre maturity are not necessarily ranked in the same order by the two sets of air permeability measurements. This indicates that the maturity term in the relation (1) above does not provide a sufficiently accurate description of the flow phenomena at different specimen compressions.

The Arealometer instrument developed by Hertel is based on this differential maturity effect and involves considering the difference between two estimates of fibre specific surface

measured at different specimen compressions. The size of the test specimen is unduly small, specimen preparation is not very quick and also leaves scope for operator differences, whilst the test results appear to be partly dependent on the previous history of the cotton's processing. For these and other reasons the method has not received widespread exploitation. Most other devices have employed larger test specimens, including the *CRITER* Maturity meter which is the most promising of the later developments, and this has eased some of the difficulties of sample and specimen preparation. However, these various procedures also appear to have the disadvantage that the test estimates of fibre maturity derived from the two airflow measurements are biased somewhat according to the fibre fineness. Samples of the same actual fibre maturity but of different variety or species not infrequently give different airflow estimates of maturity.

Investigatory work

Phase I of this project was inaugurated to investigate whether reasonably accurate and unbiased estimates of fibre maturity and linear density could be obtained from air permeability measurements made using two different test conditions.

Some limited initial experiments were made to note whether the differential maturity effect on air permeability is an isotropic effect. In one approach use was made of a holder that permitted airflow to be directed either in a direction parallel to the axis along which the specimen was compressed or perpendicular to the axis of compression. Measurements were made at four different packing densities, for each of 30 cottons, of the pressure differential P after adjusting the rate of flow Q to a suitable constant value. The ratio of the value of Q/P at the highest to the value of Q/P at the lowest specimen density increases as the fibre maturity ratio increases: this ratio would be substantially constant except for random error if the relation (1) above held exactly. Values of the correlation coefficient between maturity ratio M and the ratio of the values of Q/P for two different packing densities were calculated for (a) flow parallel to the axis of fibre compression and (b) flow perpendicular to the axis of specimen compression. The values of these correlation coefficients for three ratios of packing density are given in Table 1.

Table 1: Correlation coefficient between *M* and *Q/P*
(units of packing density are g/ml)

Direction of flow relative to the axis of compression	Ratio of specimen packing densities (high/low)		
	0.414 / 0.069 = 6	0.276 / 0.069 = 4	0.138 / 0.069 = 2
(a) parallel	0.925	0.908	0.880
(b) perpendicular	0.850	0.836	0.711

One object of the investigation was to determine whether the differential maturity effect for two packing densities was the same for both parallel and perpendicular directions. Hertel's explanation of the differential maturity effect, if true, suggests that the effect in the perpendicular direction should be opposite in sign to that of the parallel direction. The results of the present investigation show in fact that for both parallel and perpendicular directions the

ratio of the two determined values of *Q/P* increases with increasing maturity, all the correlation coefficients being positive.

The empirical relations between fibre maturity and the ratio of *Q/P* for a higher and lower packing density are closer for parallel flow than for flow perpendicular to the compression axis, the correlation coefficients in line (a) of Table 1 being higher than the corresponding values in line (b). Moreover, largely because the differential maturity effect is in the same sense for both directions of compression, there is no material advantage gained in relating the fibre maturity to the ratio of *Q/P* measured at a high density of packing to *Q/P* measured at a low density of packing and with the direction of flow at right-angles to that at high density. Further details are given in *Conclusions 1*.

The higher correlation coefficients given in Table 1 for flow parallel to the direction of specimen compression are largely a consequence of the lower test variation for this mode of flow. This is shown by the following analysis of the test data giving the computed values of standard deviation characterizing the variation in single estimates of *Q/P* from one test specimen to another test specimen of the same cotton sample.

Table 2: Standard deviations of single estimates of *Q/P*
(as % of mean value)

Flow direction relative to the axis of compression	Specimen density (g/ml)			
	0.069	0.138	0.276	0.414
(a) parallel	3.4	2.5	3.0	4.1
(b) perpendicular	5.6	4.9	4.8	5.8

These initial experiments indicated, on grounds of both accuracy and simplicity of method, the desirability of concentrating all further work on flow measurements along the axis of fibre compression.

In the following major part of the investigation, use was made of a holder consisting of a cylindrical body with a perforated circular base. Slightly smaller diameter cylinders, each with a perforated end plate and of a particular length, could be inserted into the first cylinder which had been previously packed with a randomly arranged test specimen of known weight. A total of 19 sets of data were obtained as the investigation proceeded. Each set consists of tests made by several operators on specimens taken from each of a total of either 30 or 100 cottons, at a particular specimen weight, compressed to a particular length and therefore having a particular packing density. In most instances the pressure differential *P* measured from one end of the specimen to the other was obtained after adjusting the flow rate to a suitable fixed value. This procedure yields more accurate estimates of the variation in the ratio *Q/P* because the pressure differential was measured on a manometer with a reading accuracy of about 0.04% of maximum scale value (a 0-600 mm water gauge), but for one or two short series *Q* was measured for a constant value of *P*.

A statistical analysis was made of the sets of test data to obtain the components of variance characterizing the variability of test determinations of *Q/P* yielded by a cotton sample. For convenience these component variances are expressed as percentage standard deviations, one assessing the variation between a single determination of *Q/P* and a repeat determination after

extracting and re-packing the test specimen, the second measuring the variation in values of *Q/P* yielded by different test specimens of the same sample (after eliminating operator and long-term time effects) and the third component characterizing the overall variation between the results for one operator and those for another operator on a different occasion. Separate graphical plots of these three standard deviations against the corresponding specimen density showed that each tended to assume a minimum value for a specimen density roughly in the range 0.2 to 0.4 g/ml. Smoothed curves drawn through the three sets of plotted points yield the following estimates of the average levels of the component standard deviations.

Table 3: Values of percentage standard deviation of the ratio *Q/P*

Source of variation	Specimen density (g/ml)						
	0.07	0.10	0.20	0.30	0.40	0.50	0.60
Repeat packing of same test specimen (σr)	2.2	1.5	0.8	0.9	1.1	1.7	2.2
Different test specimens (σs)	2.4	1.9	1.4	1.5	1.7	1.8	2.0
Different operators and occasions (σo)	1.8	1.3	0.7	0.5	0.6	1.0	1.4

Preliminary analysis of some of the earlier sets of the experimental data showed that the quantities *log(Q/PH)* and *log(M)* are linearly related in a manner leading to an equation of the form

$$Q/P = b \,.\, M^n.H \qquad (2)$$

which provides a better description of the variation in air permeability with fibre maturity and fibre fineness than is offered by the basic theoretical relation of equation (1) above. The available sets of data were all analysed to obtain numerical values of the constants *b* and *n* from the regression of *log(Q/PH)* on *log(M)*. The results obtained are given in *Appendix A*. A plot of the values of *n* against the corresponding values of specimen packing density shows that *n* increases markedly as the density increases. From a smooth curve drawn through the plotted points the following values of *n* typify the nature of the relation.

Table 4: Variation of exponent *n* with specimen packing density

Specimen packing density (g/ml)	<0.12	0.2	0.3	0.4	0.5	0.6
Exponent in relation (2)	1.0	1.25	1.55	1.85	2.15	2.55

If equations of the form (2) above provide valid descriptions of the dependence of air permeability (in terms of the ratio *Q/P*) on the fibre character it follows that the ratio of the permeability of a specimen measured at a high density to the permeability measured at a low density should be closely proportional to a power of *M* alone, the arithmetical division of the quantities eliminating the unknown sample value of linear density. Conversely, the fibre

maturity would vary as the ratio of air permeabilities measured at different specimen packing densities and raised to an appropriate power.

On one series of observations conducted by four operators, each testing all of the main group of 100 cottons, the pressure differential *P* along the specimen was measured at a fixed value of flow *Q* in turn for each of six specimen packing densities. The compressions to these densities were chosen on the basis of results of a preliminary analysis of earlier groups of tests, the object being to obtain six relations of the form (2) above in which the values of the exponent *n* increased in turn by an amount of about 0.25. Denoting the average determined values of *P* for these packing densities, from low to high compression, by *P1*, *P2*, … *P6*, the step difference of 0.25 for *n* in the six relations of form (2) indicates that the maturity ratio *M* would be expected to be closely proportional to the functions of *P* given in the first line of the following table.

Table 5: Dependence on Maturity Ratio of ratios of pressures at different specimen packing densities

Function of pressure differentials	$(P1/P3)^2$	$(P3/P5)^2$	(P1/P5)	$(P2/P4)^2$	$(P4/P6)^2$	(P2/P6)
Constant *c* of relation between *M* and pressure differentials	0.785	0.906	0.843	0.750	0.700	0.725
Standard error of predicted values of *M*	0.046	0.045	0.044	0.043	0.044	0.045

The variation in the ratio of two pressure differentials becomes increasingly dependent on the fibre maturity as the ratio of the two packing densities increases. However this does not necessarily result in the most accurate prediction of fibre maturity being given by the ratio of two pressure differentials measured at greatly different packing densities. As may be seen from Table 5 above, the lowest standard error characterizing the differences between actual values of M and values predicted by use of the airflow relation

$$M = c \,.\, (P2/P4)^2 = 0.75(P2/P4)^2 \qquad (3)$$

involves intermediate packing densities. Other relations based on the use of pressure differentials at the lowest density (giving *P1*) or the higher packing densities (giving differentials *P5* and *P6*) yield slightly higher prediction errors.

Using equation (3) the values of maturity ratio *M* were calculated for each of the 100 cottons. The correlation coefficient between the actual measured values of *M* and the values predicted by the relation (3) was computed to be $r = 0.910$. These predicted and actual values were plotted graphically and it was noted that the predictions were not wholly free from bias. For coarse cottons of high linear density the predicted values of *M* tend to be higher than the

actual values; conversely fine cottons of low linear density yield airflow estimates of fibre maturity ratio that tend to be somewhat lower than the actual values.

This bias in the values of *M* given by (3) suggests that the breakdown in the theoretical flow description (1) is more complex than implied by assuming relation (2). To remove the bias, and for convenience in numerical manipulation of the data, it seems appropriate to consider whether a more general relation of the form

$$Q/P = d \,.\, M^n.H^m \qquad (4)$$

may be used to obtain unbiased estimates of both *M* and *H* when the air permeability *Q/P* is measured at two packing densities and both exponents *n* and *m* take different values for different packing densities.

The six sets of data considered above were re-analysed by determining the multiple regression of *log(M)* on the logarithms of two pressure differentials (each measured at a constant flow *Q*), equivalent to a regression equation

$$Log(M) = constant \,.\, log(Pr) + constant \,.\, log(Ps) \qquad (5)$$

with *r* and *s* assuming values between 1 and 6 as appropriate. The multiple regression coefficient was calculated for each combination of lower packing density (with values of *r* from 1 to 5) and higher packing density (with *s* taking values 2 to 6, subject to $s>r$). The computed values are given in Table 6.

Table 6: Values of multiple correlation coefficient

Specimen packing density (g/ml)		0.113	0.195	0.284	0.367	0.462
Pressure at lower compression		P1	P2	P3	P4	P5
Specimen packing density (g/ml)	Pressure at higher compression					
0.195	P2	0.909	~	~	~	~
0.284	P3	0.916	0.902	~	~	~
0.367	P4	0.935	0.942	0.903	~	~
0.462	P5	0.926	0.923	0.923	0.871	~
0.542	P6	0.924	0.920	0.918	0.882	0.839

The highest value of the multiple correlation coefficient in Table 6 is 0.942 and occurs with the initial pressure differential P2 measured at a packing density of 0.195 g/ml and the second determined pressure differential P4 measured at a packing density of 0.367 g/ml.

For tests made at these packing densities of 0.195 and 0.367 g/ml the multiple regression yielded the constants in expression (5) which was then transformed to give the relation for predicting *M* from *P2* and *P4* in the form

$$M = 0.395 \,.\, P2^{0.11} \,.\, (P2/P4)^{2.5} \qquad (6)$$

The corresponding equation for predicting the average linear density *H* from the test values of *P2* and *P4* was determined in a similar manner by computing the linear multiple regression of *log(H)* on *log(P2)* and *log(P4)* and found to be

$$H = 52500 \,.\, 1/P2 \,.\, (P4/P2)^{2.5} \qquad (7)$$

Predicted values of the standard fibre weight per cm *Hs* may be obtained most easily by use of the fundamental physical relation *Hs = H/M* and substituting the values of *H* and *M* predicted by (6) and (7), or by the equivalent logarithmic transforms.

For each of the 100 cotton samples that were tested the predicted values of *H* and *M* were calculated from *P2* and *P4* using the logarithmic forms of (6) and (7), and the predicted values of *Hs* by division as indicated in the preceding paragraph. Table 7 gives for each of these fibre characters the correlation coefficient between actual and predicted values, the standard error characterizing the variation between actual and predicted values and the corresponding coefficients of variation found by expressing these standard errors as percentages of the corresponding mean values.

Table 7: Accuracy of estimating fibre maturity and fibre fineness from two measured air permeabilities at different specimen packing densities

	Correlation coefficient between actual and predicted values	Standard deviation of differences between actual and predicted values	Coefficient of variation between actual and predicted values
Maturity Ratio (*M*)	0.934	0.035	3.8 %
Average linear density (*H*)	0.994	6.8 mtex	3.5 %
Standard fibre weight per cm (*Hs*)	0.981	11.5 mtex	5.5 %

Table 8 gives the values of *M, H* and *Hs* obtained from the established direct tests on the set of 100 cottons and also the airflow estimates of these quantities. Graphical plots of the data for *M* and *H* are given in Figs 1 and 2, and may be observed to obtain a visual appreciation of the closeness of agreement, supplementing the statistical measures given in Table 7.

It is pertinent to observe that the first modification of the airflow relation based on classical theory, in the form of equation (3), enabled estimates of fibre maturity to be obtained from measured pressure differentials at two packing densities. For the best combination of pressure differentials this relation gives a correlation coefficient of 0.910 between actual and predicted values; the corresponding standard error of the difference is 0.043. To eliminate some bias in the predicted results for maturity ratio that followed from the application of (3), the more complex form of (4) gives scope for the importance of both *M* and *H* to vary with increasing packing density.

The corresponding equations (5) or (6) for predicting *M* from the best combination of the pressure differentials (P2 and P4) gives an increased correlation coefficient of 0.943 between

actual and predicted values and a lower standard error of 0.035. The ratio of the variances $(0.035)^2 / (0.043)^2 = 0.66$ is a reduction that is both material and statistically significant.

Table 8: Comparison of airflow estimates of maturity ratio, average linear density and standard linear density with directly observed test values

	Direct measure			Airflow estimate				Direct measure			Airflow estimate		
Sample	**M**	**H**	**Hs**	**M**	**H**	**Hs**	**Sample**	**M**	**H**	**Hs**	**M**	**H**	**Hs**
1	0.93	144	155	0.917	144	157	**51**	0.94	136	145	0.848	153	180
2	1.06	340	321	1.027	333	324	**52**	0.83	156	188	0.820	157	191
3	0.865	167	193	0.873	170	195	**53**	1.09	353	324	1.055	362	343
4	1.05	288	274	1.051	283	269	**54**	0.74	145	196	0.776	142	183
5	0.64	104	163	0.583	95	163	**55**	0.765	120	157	0.741	123	166
6	0.815	199	244	0.894	199	223	**56**	0.95	205	216	0.941	201	214
7	0.975	337	346	0.948	326	344	**57**	0.995	194	195	0.924	196	212
8	1.035	166	160	0.989	169	171	**58**	0.96	255	266	0.924	260	281
9	0.74	164	222	0.725	158	218	**59**	0.95	224	236	0.944	235	249
10	0.815	109	134	0.818	116	142	**60**	0.965	202	209	0.953	205	215
11	0.835	198	237	0.847	194	229	**61**	0.98	195	199	0.928	188	203
12	0.88	180	205	0.871	182	209	**62**	0.89	140	157	0.819	137	167
13	1.065	203	187	1.075	201	187	**63**	1.04	283	272	1.052	281	267
14	0.94	239	254	0.988	236	239	**64**	0.965	326	338	0.947	332	351
15	0.98	323	329	0.974	323	332	**65**	0.98	336	343	0.940	322	343
16	0.865	181	209	0.934	194	208	**66**	0.99	327	330	0.929	328	353
17	0.745	148	199	0.766	145	189	**67**	1.03	191	185	1.021	192	188
18	0.985	140	142	0.962	142	148	**68**	1.01	190	188	1.030	186	181
19	0.88	99	113	0.835	96	115	**69**	0.985	200	203	0.987	189	191
20	1.04	198	190	1.018	188	185	**70**	0.72	162	225	0.797	168	211
21	0.825	153	186	0.818	161	197	**71**	0.88	127	144	0.880	132	150
22	1.05	282	286	1.066	286	269	**72**	0.875	195	223	0.932	189	203
23	0.835	135	162	0.831	139	167	**73**	0.86	181	210	0.892	169	189
24	0.715	170	238	0.766	183	239	**74**	0.865	173	200	0.901	179	196
25	0.885	102	115	0.869	107	123	**75**	0.945	213	225	0.999	213	213
26	0.63	137	218	0.600	148	247	**76**	0.98	188	192	0.944	194	206
27	0.97	261	269	1.000	254	254	**77**	0.825	177	215	0.869	162	186
28	1.095	395	361	1.062	393	370	**78**	0.97	148	153	0.949	147	155
29	0.895	305	341	0.890	316	355	**79**	0.89	193	217	0.886	180	203
30	0.825	223	270	0.866	231	267	**80**	0.84	150	179	0.811	144	178
31	0.945	143	151	0.943	141	150	**81**	1.065	190	178	1.037	192	185

	Direct measure			Airflow estimate				Direct measure			Airflow estimate		
Sample	**M**	**H**	**Hs**	**M**	**H**	**Hs**	**Sample**	**M**	**H**	**Hs**	**M**	**H**	**Hs**
32	0.975	135	138	0.930	139	149	**82**	0.88	126	143	0.888	122	137
33	0.94	183	195	0.940	185	197	**83**	0.995	136	137	0.997	143	143
34	0.90	183	203	0.922	182	197	**84**	0.91	127	140	0.896	129	144
35	0.825	193	234	0.875	193	221	**85**	1.045	149	143	1.021	153	150
36	0.98	137	140	0.939	140	149	**86**	0.945	149	158	0.950	152	160
37	0.85	171	201	0.939	170	181	**87**	1.065	193	181	1.052	185	176
38	0.80	136	170	0.840	139	165	**88**	1.045	191	183	1.017	190	187
39	0.875	173	198	0.872	164	188	**89**	0.935	147	157	0.931	145	156
40	0.845	164	194	0.827	184	222	**90**	0.925	219	237	0.971	230	237
41	0.875	194	222	0.896	197	220	**91**	0.94	225	239	0.972	227	234
42	0.925	203	219	0.954	202	212	**92**	1.025	213	208	1.055	207	196
43	0.90	172	191	0.896	162	181	**93**	0.935	184	197	0.944	185	196
44	0.90	196	218	0.980	183	187	**94**	0.94	190	202	0.948	186	196
45	0.75	147	196	0.775	135	174	**95**	0.92	180	196	0.951	181	190
46	1.005	187	186	1.040	186	179	**96**	0.92	143	155	0.897	140	156
47	1.005	141	140	0.960	138	144	**97**	0.84	159	189	0.835	160	192
48	0.95	190	200	0.943	187	198	**98**	0.975	136	139	0.960	145	151
49	1.045	272	260	1.061	273	257	**99**	1.01	320	317	1.007	316	314
50	1.015	357	352	0.985	351	356	**100**	1.045	255	244	1.039	250	241

Figure 1: Accuracy of two-level airflow instrument

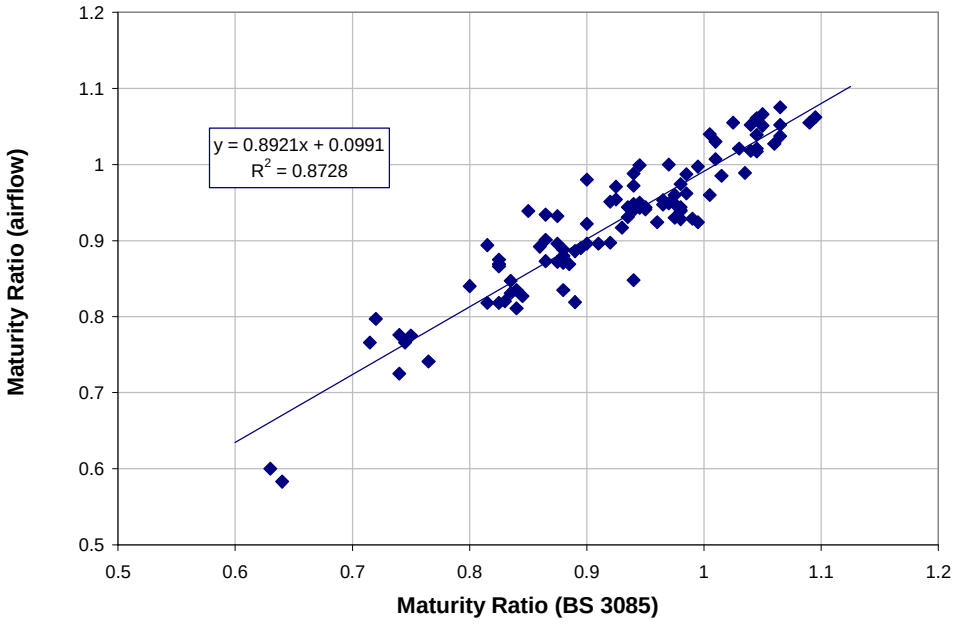
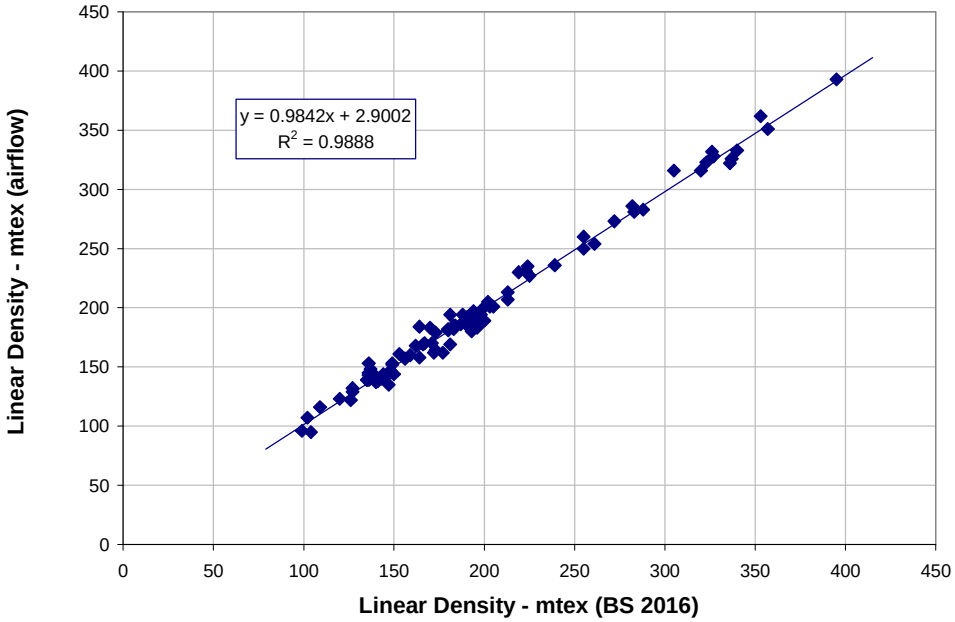


Figure 2: Accuracy of two-level airflow instrument



Conclusions

The purpose of this investigation was essentially to establish appropriate test conditions that would enable estimates of fibre maturity and fineness to be obtained from measurements of air permeability with reasonable balance between requirements for accuracy and those for ease of operation. This aim has been pursued by making various sets of permeability measurements under different test conditions and using a range of cottons differing widely in both maturity and fineness to ensure general applicability of any findings. Analysis of the numerical data of these trials and also of the fundamental aspects of the problem leads to the following conclusions.

1. Direction of air flow

The effects of fibre maturity and fibre linear density on the air permeability of a test specimen plug of raw cotton vary with the specimen packing density and the direction of flow relative to the direction of plug compression. The differential effect of fibre maturity on the air permeability of a test specimen plug, as the degree of specimen compression alters, is similar in sign but not necessarily in magnitude for flow along the axis of compression and flow at right-angles. As a test specimen is compressed, fibres that were initially packed at random into a holder become increasingly arranged in a plane perpendicular to the axis of compression. There appears to be a greater effective uniformity in packing along the axis of compression than in the perpendicular direction. Certainly the variation in repeat determination of air permeability made on the same sample is appreciably and consistently larger for tests made in the direction perpendicular to the axis of compression.

The ratios of air permeabilities measured at two different degrees of compression vary with maturity more closely for flow measured parallel to the axis of compression than for perpendicular flow. Moreover the ratio of two air permeabilities in the parallel direction are correlated more highly with the maturity ratio *M* than either of the ratios involving

permeabilities measured in different directions. For example, in Table 1 for the 6:1 ratio of packing densities, the correlation coefficient between *M* and the ratio of permeabilities measured parallel to the axis of compression is 0.925. This is larger than the corresponding correlation for the ratio of permeability measurements (final/initial perpendicular) for which *r = 0.889* and the ratio of permeabilities (final perpendicular/initial parallel) for which *r = 0.905*.

These findings lead to the conclusion that two determinations of the air permeability of plugs both measured parallel to the axis of compression but each at a different packing density give the best conditions for assessing indirectly the fibre maturity of a sample of cotton.

2. Packing densities

For plugs at low packing densities of about 0.1 g/ml or less there is the closest dependence of air permeability on the simple product *MH* of maturity ratio and linear density, the relation indicated by classical theory. Some gain in simplicity would be achieved if one of the two air permeability determinations could be made at low density in this region. Nevertheless as the plug density is reduced to 0.1 g/ml or lower there is a steady increase in heterogeneity of its structure, thus giving an appreciable increase in the testing errors associated with repeated determinations and with different operators. Particularly at densities of about 0.08 g/ml and lower it has also been observed that the specimen plug structure becomes unstable. A quick surge of air entering the specimen holder at one end causes the fibres to move partly towards the other end, causing a gradient along the holder in the packing density and so affecting the reproducibility of the determinations.

At the other end of the density scale, particularly as the plug density exceeds 0.5 g/ml, there is an increase in the differential effect of fibre maturity, i.e. the greater the fibre maturity the greater is the increase in ratio of air permeability at a high compression to that at a low compression. This increasing maturity effect was studied over a range of ratios of packing density up to 10:1, with the higher packing density exceeding 0.6 g/ml. It was found that repeat test variation and operator effects increase appreciably with increasing packing density, thus off-setting the advantages derived from the increased differential maturity effect.

The various testing errors are at their lowest in the region between about 0.2 and 0.4 g/ml. Furthermore analysis of several sets of data shows that the ratio of two air permeability measurements made at densities of packing at about the boundaries of this range give the most accurate estimates of fibre maturity. Nevertheless the variation in such accuracy is not pronounced for even moderate departures of the packing densities from these two limits of 0.2 and 0.4 g/ml. The exact choice of packing densities may therefore also take into account other practical considerations.

3. Size of test specimen

It is undesirable to have a specimen of unduly large size. There are increased difficulties of ensuring that the specimen is of uniform density throughout if it requires to be packed into an unduly long holder. Moreover with large specimens there is the increased time arising from increased handling. Equally in some fields of work, for example the early stages of cotton breeding, test results are frequently required from small samples. If samples are very small, less than about 2 grammes, the compressed length of the specimens becomes unduly short and so gives rise to higher errors in repeat determinations and to the need for greater accuracy in constructing the specimen holders.

For most purposes a specimen weight of 4 grammes is considered to be of the right order, giving rise to few packing difficulties, permitting repeat tests to be made on fresh specimens

drawn from laboratory samples of the size normally encountered (usually in the range 20-100 grammes), and avoiding the need for undesirably small holders.

4. Size of specimen holder

For a given size of test specimen there is scope for a range of combinations of length and diameter giving a particular volume. An unduly narrow holder is difficult to pack uniformly along its length. A holder of unduly large diameter is difficult to pack evenly over its cross-sectional area and has the further disadvantage of giving a very short length of compressed specimen. In this and other experiments a diameter of $1^1/_8$ inch has given rise to no essential difficulties. It is preferable to have a depth of about 3 inches available for packing the loose cotton inside: with a materially shorter length the fluffy mass protrudes and makes insertion of the second perforated end of the holder difficult.

In the present series of tests the most suitable initial packing density was 0.195 g/ml which was given by using an internal holder length of 32 mm. The second determination was that of the pressure differential *P* made at a packing density of 0.367 g/ml given by an internal specimen holder length of 17 mm.

The following holder dimensions are recommended

Diameter:	28 mm
Minimum total internal length	
available for initial insertion of test specimen:	75 mm
First compression, internal length:	34 mm
Second compression, internal length:	17 mm

The first and second compressions, using a specimen of mass 4 grammes, give packing densities of 0.1911 g/ml and 0.3821 g/ml.

5. Measurement of air permeability

One means of measuring air permeability conveniently and quickly is to insert in the circuit a constant pressure air controller and to read off on a flowmeter the corresponding rate of flow. This method is not sufficiently accurate. The accuracy of control of air pressure at a constant difference below atmospheric pressure, using available instruments, may be subject to errors of 1% or more. The measurement of the rate of flow of air by means of a calibrated rotameter type of flowmeter is subject to errors of around 2%, fluctuating according to the position along the flow scale. Because of the nature of the relations between maturity and air permeability, the effects of such errors on the magnitude of the estimates of fibre maturity (and fineness) are magnified. Observational errors of the order 2% would lead to much larger percentage errors in the derived estimates of the fibre characters, errors that would render the test largely useless for most practical purposes.

A more feasible procedure is to use a means of drawing air through a test specimen at a constant rate of flow. Initial examination of the performance of some manufactured equipment suggests that control to a particular flow value is feasible with short-term variation appreciably less than 1%. Of necessity the flow would be delivered as a volume flow at a pressure differential below atmospheric pressure equal to the measured pressure differential across the ends of the test specimen, and therefore a somewhat pressure-dependent variable flow in terms of volume per unit time entering the specimen chamber. However, from a practical aspect, this pressure dependence may be eliminated by choice of an appropriate algebraic relation in effecting the calibration procedure.

With a constant flow device, the air permeability of specimens would be assessed by measuring the corresponding pressure differential across their ends, as in most of the current

investigation. Reference to equations (6) and (7) shows that both fibre maturity and fibre fineness estimates are largely determined by the ratio of the two observed pressure differentials raised to a particular power: in the present series the exponent was 2.5. Thus any random errors involved in the determination of the pressure differentials produce appreciably greater proportional effects on the estimates of the fibre characters. If a precision differential pressure meter had an error of about 0.1% at full-scale deflection, in many instances this implies an error of about 0.4% in the region of the scale where most cottons would give test values (i.e. at about $^2/_5$ along the scale from zero). If the error were wholly random the present investigation suggests that the ratio of the two pressure differentials might produce an associated error in the estimate of fibre maturity of perhaps about 0.4 * √2 * 2.5 or 1.4%. (For comparison it may be noted that a water manometer was used in the present experiments with adjustments made and readings taken to 0.2 mm but generally only reliable to about 0.5 mm or approximately 0.1% of the maximum full-scale reading of 600 mm).

If the accuracy of the measurement of air pressure differential is appreciably poorer than that implied by a figure of 0.1% of full-scale value it is considered that the fibre character estimates will be subject to additional instrumental errors of magnitude greater than those arising from random sampling and packing variation. Certainly single differential pressure meters with an accuracy of the order 1/300 or 0.33% full scale value appear to be unsatisfactory. However the accuracy may be materially improved by the use of two pressure gauges covering different ranges, to avoid using the low end of one of the scales.

6. Range of gauges for measurement of pressure differential and flow

Each test determination involves the reading of the pressure difference across the ends of the specimen at each of the two compressions. On each occasion a flow controller operates automatically, but there needs to be an adjustment of each of the two constant flow devices to check against a flowmeter that the setting is correct. To some degree the total range on the pressure differential meter will depend on the availability of models of satisfactory accuracy.

Subject to the requirements given in the preceding section, if a pressure differential meter of 0-500 mm of water gauge were fitted to the instrument, holders of the type suggested and specimens of 4 g mass would require an initial constant rate of flow of about 180 litres of air per hour, or 50 ml/sec. After compression the second constant rate of flow would be about 45 litres of air per hour, or about 12.5 ml/sec. Conditions of flow through the specimen plugs is substantially linear. Thus if the differential gauge for pressure were 0-1000 mm of water there would need to be provision for checking and adjustment of flow rates to about twice the values of the rates suggested above.

7. Operator differences

Most of the present series of individual sets of observations have been on a scale sufficiently large to permit the detection of small operator differences. Observation indicates that such differences are unlikely to have arisen from manipulation of instrumental controls or from taking instrument readings. It is more probable that the differences arise from small variations in the manner in which the test specimens are packed into the empty holder. Although efforts are taken to ensure the cotton is placed evenly, by feeling and pressing with a finger whilst feeding the cotton into the holder, there are likely to be some packing density fluctuations along the holder. Apparently these are only partly removed when one end of the holder is moved to compress the specimen first to the lower packing density and then again to the second and more compact form.

It is considered that compression of the initially loose test specimens by effecting relative motion between the fibre mass and both perforated end caps of the holder would lead to a more homogeneous mode of packing.

APPENDIX A

Summary of 19 sets of data of pressure difference measured at constant flow over a range of packing densities and several sizes of holder

(specimen diameter is always $1^1/_8$ inch = 28.575 mm)

Expt	D g/ml	M g	L mm	Ns	No	σr %	σs %	σ %	σo %	a	n	r
A	0.061	2.5	63.5	120	4	2.1	2.4	3.2	1.3	36.9	0.99	0.78
F, L1, M4	0.098	4	63.5	230	12	1.5	1.5	2.1	1.9	16.4	0.90	0.84
J	0.111	8	63.5	30	4	1.4	1.8	2.3	1.3	23.1	1.05	0.81
N1	0.113	4	55	100	4	1.9	1.3	2.3	1.4	14.4	0.89	0.87
M3	0.123	4	50.8	100	4	1.3	1.3	1.8	1.5	13.3	0.99	0.85
B	0.123	5	63.5	30	4	1.2	2.2	2.5	1.8	10.5	1.08	0.84
N2	0.195	4	32	100	4	0.8	1.5	1.7	0.5	8.11	1.15	0.88
M2	0.196	4	31.75	100	4	0.8	1.3	1.5	0.5	8.00	1.25	0.87
C	0.205	5	38.1	30	4	~	~	2.2	0.4*	6.07	1.40	0.85
G	0.246	4	25.4	30	4	~	~	1.7	0.7	6.02	1.50	0.86
N3	0.284	4	22	100	4	1.0	1.5	1.8	0.6	4.90	1.43	0.89
H	0.327	4	19.05	30	4	~	~	1.9	0.5	3.93	1.76	0.88
N4	0.367	4	17	100	4	1.1	1.6	2.1	0.9	3.11	1.63	0.90
D	0.409	5	19.05	30	4	~	~	2.4	0.2*	1.98	2.05	0.87
N5	0.462	4	13.5	100	4	1.5	1.8	2.4	1.4	1.97	1.89	0.90
I, M1, L2	0.491	4	12.7	230	12	1.7	1.8	2.5	1.2	1.71	2.11	0.90
N6	0.542	4	11.5	100	4	1.6	2.1	2.7	1.8	1.33	2.06	0.90
K	0.553	8	12.7	30	4	2.1	1.9	2.8	0.6	2.25	2.44	0.87
E	0.614	5	12.7	30	4	2.2	1.8	2.8	0.9	2.67	2.58	0.88

Notes

D specimen packing density
M specimen mass
L specimen length (NB some lengths, originally quoted in inches, converted to mm)
Ns number of cotton samples
No number of operator/occasions
σr percentage standard deviation of repeat tests on same specimen, after repacking
σs percentage SD characterizing real variation between test specimens of same sample
σo percentage SD characterizing the overall variation between different operators and different occasions

σ	SD characterizing the variation in results of single tests made on different specimens by the same operator, given by $\sigma = \sqrt{(\sigma r^2 + \sigma s^2)}$
~	separate estimates of σr and σs not available: tests made with only one packing, giving estimate of σ only
*	not statistically significant
r	correlation coefficient between *log(Q/PH)* and *log(M)*
a, n	parameters of the equation $Q/P = a \,.\, 10^{-3} \,.\, M^n.H$
Q	rate of airflow in litres / hour
P	measured pressure difference in mm of water
M	fibre maturity ratio
H	fibre linear density

Development of Rapid Method of Measuring Cotton Fibre Maturity and Linear Density

by

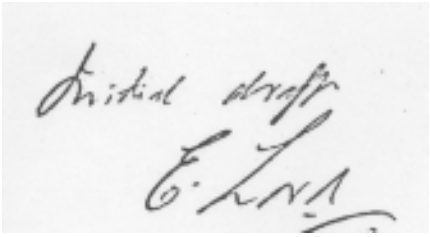
E. Lord, Shirley Institute, Manchester

Phase II of the Research Project S 70 P10
Sponsored by the International Institute for Cotton
1 October 1970 - 30 September 1971

Project Leader: Dr. K Greenwood

This report includes recommendations concerning the essential requirements of any instrument, trials of the instrument that was made and received, trials of the second instrument, instrument operation, calibration etc.

March 1973.



Note: This is an "electronic" version of Mr Lord's report. The original report was scanned into *Omnipage Pro*, in July 2006, and edited in *MS Word*. The original was a photocopy of a draft document that had been produced with a manual typewriter and, therefore, a great deal of editing and correction was necessary after the *OCR* process. Although the resulting text has been checked carefully, it is possible that some transcription errors have escaped. All of the tables have been reconstructed in *MS Excel* using the calibration formulae given in this text. This has had the result that, in the tables of calibration data for the 100 test samples, some of the values are not identical with those originally given by Edmund Lord. No doubt most of these differences are due to rounding "errors" and to the fact that Lord (or his technician) was using the (mechanical?) desk calculators of the time. The two graphs that appear in Appendix A, and the one in Appendix B were not included in the original reports.

CONTENTS

Phase II

The main purpose of phase II was to build a prototype instrument based on the findings of Phase I concerning optimum conditions of test for estimating fibre maturity and fineness from two measures of air permeability at different specimen densities.

Accordingly Dr. Greenwood arranged that the Instrument Design Section should produce the instrument.

Note 1. Later a second prototype instrument appeared. The position is not at all clear regarding how this was constructed in relation to Phase II of the project. Certainly the draft of the terms of the Phase II agreement that were available does not appear to embrace this aspect. However a second instrument was made. It was not possible to compare this instrument with the first which was on trial at Courtaulds in 1972, from Spring until late in the year.

Because of lack of staff and pressure of other work the comparison was not effected until a few weeks later, in the week commencing February 12, 1973. The comparison was necessarily brief and limited, because IIC wished to send the first instrument for a further trial to Bremen. Details of the comparison are given in a separate section of this report.

Note 2. Following the calibration of the first instrument, autumn 1971, it was intended that the instrument should be tried in the laboratory. The results furnished by the instrument are not measures of the fibre characters, only indirect estimates, and as such in any critical work of the type covered by our normal routine tests the accuracy is not sufficient due to the operation of other disturbing factors. Nevertheless in the early stages of cotton breeding work, and for some aspects of commercial selection, the estimates could be used to exert quite a strong selection pressure towards aiming for higher fibre maturity without accompanying increase in coarseness, or for fineness without risking undue shifts towards immaturity. To assess the strength of such selection pressure it was originally intended to run tests simultaneously with our normal tests. However the drastic redundancy programme of November 1971 / March 31, 1972 made it necessary to concentrate as much work as possible on the normal CRC programme. The seasonal movement starts in December of each year, and because of the redundancies added to the previous numbers of non-replacements it was essential to finish the early material whilst testing staff were available.

This section of the report is concerned solely with the calibration of the first prototype instrument. The instrument was delivered July 19 and then returned for rectification of several faults. Alteration was necessary in the wiring circuit, and a small leakage needed to be eliminated. Some initial trials to establish a test procedure were made August 6-15. The main series of tests to establish the calibration then followed in the latter part of August and in September, 1971. The results of the calibration are given in the following pages.

The results were communicated to IIC, but no formal report was made because the experimental work essentially consisted of a calibration which was in numerical form. However In January 1972 a detailed summary of the work was made to IIC so that Bill J. Naarding could include it in a paper that he was to give to the Bremen biennial conference.

Essential requirements for a prototype instrument

The following details were supplied to the Instrument Section for incorporation in the design of the instrument to be built under Phase II of the contract.

Specimen holder

Diameter	28 mm
Length available for packing	75 mm
Length under first compression	34 mm
Length under second compression	17 mm

Specimen weight

4 g to give 0.1911 g/ml and 0.3821 g/ml for first and second compressions.

Ease of packing and uniformity of density

Walls of the cylindrical chamber to be highly polished, to reduce friction to minimum.

Permit relative motion between cylinder and both end plates when cotton is compressed: this is to give greater uniformity of compression along the length of the specimen, especially at high compression.

Rotameter flowmeter

Two flow controllers (Flostats), one operating at initial low compression and other at the high compression.

First compression: fine needle valve to set flow at 4 l/min.

Second compression: similar valve to set flow at 1 l/min.

Note The flows will be set at these values with nothing in the specimen chamber, so that the air pressure is atmospheric. With a specimen in the holder there will be a drop in the indicated marking of the rotameters, air now passing at less than atmospheric pressure but the setting will be left unchanged

Note 2 In making subsequent instruments it is essential that the 4 and 1 litres/min markings agree exactly with those of the initial instrument. Direct comparison is best because a makers calibration cannot be guaranteed to closer than 1-2% except by special calibration procedures.

Possibly blank flowmeters should be obtained after the first and the markings put on by the instrument maker or checker.

Pressure gauges

An accuracy of 0.1% of full scale reading for the pressure gauge is most desirable. For a very coarse cotton of high maturity the pressure differential along the specimen may be about 1/10 that of a very immature fairly fine cotton. Such coarse cottons, at the low end of the pressure range, will therefore be subject to an error in measurement of about 1% assuming that the sensitivity and error amounts to 0.1% of full scale deflection.

a) A digital pressure gauge was considered. This would be suitable because the accuracy is about 0.05% of full scale value. Being of fairly recent development the price is still excessive, but it should be kept in mind for when production gets under way.

b) The Wallace and Tiernen two revolution, gauge has an accuracy of 0.1% full scale value. Again it appears to be too expensive for incorporation.

c) Adopted for cheapness is the plan of using two W & T 6" gauges, accuracy 0.33% full scale. The first would be scaled 0-250 mm water. The second would be scaled 0-500 mm water but there would be automatic switching to this second one so that it became operative only for use in the range 250-500 mm. This plan would give an accuracy of about 0.5% for an average cotton.

Note This choice of two pressure gauges entailed fitting switches which operated at 250 mm water pressure (to switch flow to the 0-500 mm gauge) and also at 500 mm (to sever the circuit from the pressure gauge when the pressure differential along the specimen exceeded 500 mm, e.g. by accident).

Accuracy of holder

This was considered empirically and on the basis of Kozeny theory.

Approximately it was found that a 1% increase in packing density caused approaching a 3% change in air permeability.

There should be little or no engineering problems in ensuring that the internal length of the specimen holder is correct to about 0.02 mm.

The diameter with an accuracy of about 0.02, preferably approaching 0.01mm, would give no material change in measures of the pressure differentials from expectation.

Accuracy of pressure gauges on first prototype model

Both gauges were checked exhaustively before incorporation in the instrument (against the sensitive paraffin-filled manometer calibrated in mm of water).

Checks were made at 10 mm intervals.

In the range 250-500 of the 0-500 mm gauge the maximum error noted amounted to 0.6 mm for the 260 mm reading. This is only 0.12%, well within the makers claim of 0.33% of full scale value. (It represents 0.23% of the scale reading).

For the 0-250 mm gauge the accuracy again was well within the limits claimed by the manufacturer over nearly all the scale. Just at the top the error increased to 0.8 mm at 240 mm, practically equal to the limit of 0.33% and just shot over this for 240-250 mm. The maker's check did not show this. It would be interesting to carry out the comparison again after the gauge had been in use for some time, to see whether it had changed.

Initial trials of instrument

The instrument was not received following its final re-adjustments until August 6 leaving less than two months available for evaluation instead of the initially proposed longer period. The skilled assistant trained during the Phase I period had been transferred elsewhere and this, coupled with other non-replacement of staff made it impossible to effect a complete investigation, calibration and report in the time available because other work also had to progress.

Various trials were made to establish a test procedure.

When the specimen is compressed, either initially or on second compression, the pressure recorded does not change immediately to its final equilibrium value. Flows are not high and the volume of the system is finite (1 litre /min is about 17 ml /sec). The volume of the holder is roughly 21 ml at low compression, 10½ ml at high compression and the actual volume occupied by the 4 g of cotton is 3 ml. In addition the internal volume of the connecting tubing amounts to several ml. Thus a few seconds are required to permit stabilization to occur, even allowing for the quick exit of most air

following compression.

Trials indicated that the reading is substantially stable after about 5-10 Seconds. The procedure was adopted of allowing 5-10 seconds to elapse after inserting the top of the specimen holder, or after giving the specimen its second compression.

Note After this period there is sometimes a very slow change, probably as fibres move slightly under compression because of slow internal slippage within the holder.

Calibration procedure

Three operators were used. Each made tests on 2 specimens /sample. On each specimen pressures at low and high compression were recorded. After this the specimen was removed, fluffed out and inserted to obtain 2 more readings.

All samples of cotton were given a passage through the Miniature Card to obtain blended opened samples.

The test operations for convenience have been summarized in one section for other purposes, and are given *after* these notes on calibration. This results in some overlap but has the advantage of keeping the test procedure and normal treatment of results in a unified section.

The material used comprised 100 samples of cotton of widely different origin, maturity and fineness, substantially the same but for two or three as the group used in the Phase I of the programme.

The average results obtained are given in tabulated form, together with the test values of maturity ratio and average fibre weight per cm (*M* and *H*). Full details of the amount of such testing are given in the full account of Phase 1 of the programme, pages 13 and 14 of Section 4 of the manuscript copy of this draft of a possible open publication.

Testing time

a) The time required to weigh and make duplicate observations of two test specimens per sample is approximately 6-8 minutes.

b) Time required to prepare a 10 g sample from the bulk plus passing through a miniature card or suitable blender

Results

a) Calibration in terms of Micronaire Value

The specimen density at the lower compression is closely near that of the Micronaire tester and of similar instruments used for determining Micronaire value. Hence 1/PL will vary in a virtual one-to-one correspondence with Micronaire value.

From calibration of the first instrument with 15 of the International Calibration Cotton Standards the following relationship indicates the correspondence between Micronaire value and PL.

$$\textit{Micronaire value} = 0.60 + 850 / (PL + 40)$$

The correlation coefficient in this calibration using this transform is 0.9988

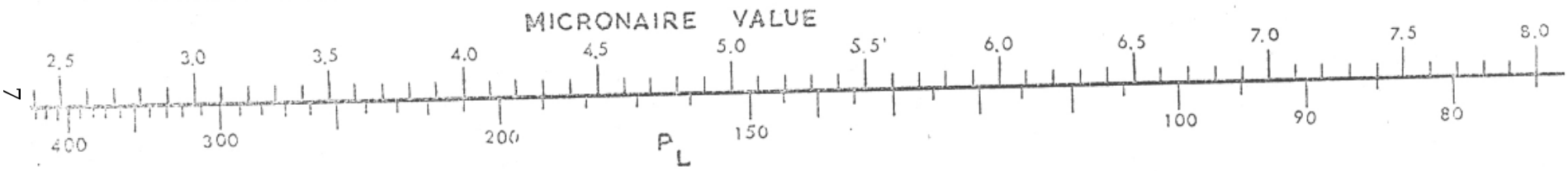
For a given value of PL in mm the corresponding value of air permeability on the Micronaire scale may be read off from the table instead of applying the above transform. The table gives Micronaire values for values of PL between 459 (corresponding Micronaire value 2.30) and 74 (Micronaire value 8.06) for increments of 1 mm in PL.

Micronaire Value for PL

PL in steps of 1 mm from 74 mm to 459 mm

PL	0	1	2	3	4	5	6	7	8	9
7					8.06	7.99	7.93	7.86	7.80	7.74
8	7.68	7.62	7.57	7.51	7.45	7.40	7.35	7.29	7.24	7.19
9	7.14	7.09	7.04	6.99	6.94	6.90	6.85	6.80	6.76	6.72
10	6.67	6.63	6.59	6.54	6.50	6.46	6.42	6.38	6.34	6.30
11	6.27	6.23	6.19	6.16	6.12	6.08	6.05	6.01	5.98	5.95
12	5.91	5.88	5.85	5.81	5.78	5.75	5.72	5.69	5.66	5.63
13	5.60	5.57	5.54	5.51	5.49	5.46	5.43	5.40	5.38	5.35
14	5.32	5.30	5.27	5.24	5.22	5.19	5.17	5.15	5.12	5.10
15	5.07	5.05	5.03	5.00	4.98	4.96	4.94	4.91	4.89	4.87
16	4.85	4.83	4.81	4.79	4.77	4.75	4.73	4.71	4.69	4.67
17	4.65	4.63	4.61	4.59	4.57	4.55	4.54	4.52	4.50	4.48
18	4.46	4.45	4.43	4.41	4.39	4.38	4.36	4.34	4.33	4.31
19	4.30	4.28	4.26	4.25	4.23	4.22	4.20	4.19	4.17	4.16
20	4.14	4.13	4.11	4.10	4.08	4.07	4.06	4.04	4.03	4.01
21	4.00	3.99	3.97	3.96	3.95	3.93	3.92	3.91	3.89	3.88
22	3.87	3.86	3.84	3.83	3.82	3.81	3.80	3.78	3.77	3.76
23	3.75	3.74	3.73	3.71	3.70	3.69	3.68	3.67	3.66	3.65
24	3.64	3.62	3.61	3.60	3.59	3.58	3.57	3.56	3.55	3.54
25	3.53	3.52	3.51	3.50	3.49	3.48	3.47	3.46	3.45	3.44
26	3.43	3.42	3.41	3.41	3.40	3.39	3.38	3.37	3.36	3.35
27	3.34	3.33	3.32	3.32	3.31	3.30	3.29	3.28	3.27	3.26
28	3.26	3.25	3.24	3.23	3.22	3.22	3.21	3.20	3.19	3.18
29	3.18	3.17	3.16	3.15	3.14	3.14	3.13	3.12	3.11	3.11
30	3.10	3.09	3.09	3.08	3.07	3.06	3.06	3.05	3.04	3.04
31	3.03	3.02	3.01	3.01	3.00	2.99	2.99	2.98	2.97	2.97
32	2.96	2.95	2.95	2.94	2.94	2.93	2.92	2.92	2.91	2.90
33	2.90	2.89	2.88	2.88	2.87	2.87	2.86	2.85	2.85	2.84
34	2.84	2.83	2.83	2.82	2.81	2.81	2.80	2.80	2.79	2.79
35	2.78	2.77	2.77	2.76	2.76	2.75	2.75	2.74	2.74	2.73
36	2.73	2.72	2.71	2.71	2.70	2.70	2.69	2.69	2.68	2.68
37	2.67	2.67	2.66	2.66	2.65	2.65	2.64	2.64	2.63	2.63
38	2.62	2.62	2.61	2.61	2.60	2.60	2.60	2.59	2.59	2.58
39	2.58	2.57	2.57	2.56	2.56	2.55	2.55	2.55	2.54	2.54
40	2.53	2.53	2.52	2.52	2.51	2.51	2.51	2.50	2.50	2.49
41	2.49	2.48	2.48	2.48	2.47	2.47	2.46	2.46	2.46	2.45
42	2.45	2.44	2.44	2.44	2.43	2.43	2.42	2.42	2.42	2.41
43	2.41	2.40	2.40	2.40	2.39	2.39	2.39	2.38	2.38	2.37
44	2.37	2.37	2.36	2.36	2.36	2.35	2.35	2.35	2.34	2.34
45	2.33	2.33	2.33	2.32	2.32	2.32	2.31	2.31	2.31	2.30

A scale showing the correspondence between values of PL and Micronaire value is given overleaf.


MICRONAIRE VALUE
2.5
3.0
3.5
4.0
4.5
5.0
5.5'
6.0
6.5
7.0
7.5
8.0
400
300
200
150
100
90
80
P L

b) Simple treatment using PL and PH

The ratio PL/PH increases with increasing fibre maturity. The quantity $(PL/PH)^2$ increases substantially linearly with the fibre maturity ratio (and hence with increasing proportion of mature fibres measured on the ASTM system). However this square and, of course, the simple ratio are slightly dependent on the fibre fineness. Intrinsically coarse cottons tend to give rather higher values of PL/PH (and its square) than much finer cottons.

To eliminate this bias according to fineness necessitated the use of a much more complex relationship (see next section). Nevertheless when dealing in a limited range of fineness, say samples of various long-staple American Upland varieties or some other fairly wide loose grouping, the amount of bias is not unduly serious. Selection on the basis of the ratio PL/PH will result in a selection pressure in the direction of increased fibre maturity largely independent of fineness.

Note As indicated in the second paragraph of the General Description of Instrument and Method of Operation, PL and PH may be used only to provide estimates and not measures of maturity and fineness. Because the flow resistance of fibre plugs is also dependent on other features that vary slightly (overall specific fibre volume, average shape of section for a given fineness and maturity), there is some limited additional variation in PL and PH over and above that arising from differences in fibre maturity and linear density.

c) Complex treatment

Statistical analysis of the main body of data relating to measurements on the 100 cottons of widely different maturity and fineness gives the following relationships for estimation of maturity and fineness.

(i) $$\textit{maturity ratio} = M = 0.247\, PL^{1/8} \,.\, (PL/PH)^2$$

Note The relation between fibre maturity ratio and percentage mature fibres of the ASTM test is given in *Journal Text. Inst*., 1956, 47, T 209

(ii) Denoting by *H* the fibre linear density (fibre weight per centimetre in millitex, i.e. 10^{-8} g/cm)

$$H = 60{,}000 / PL \,.\, (PH/PL)^{1.75}$$

Note The values of H used in the calibration of the prototype instrument were obtained from measurements made on test specimens taken from comb sorter diagrams, by cutting centimetre lengths and weighing bundles of 100. Several determinations, each based on 500 fibres per diagram, were made on each of the 100 samples.

d) Applying the prediction formulae

Although the formula for the maturity ratio is complex, it is easy to evaluate on any modern desk calculator with automatic square root operation - the time is less than many slide rule calculations applied to other types of test data. The estimate of average linear density *H* may be made similarly.

Consideration was given to providing a conventional nomogram but because the range of pressures that it would need to cover is roughly of the order of 10:l, and because PL and PH tend to increase together over the range, the nomogram would need to be exceptionally large to give moderate accuracy in reading off the value of fibre maturity ratio *M*. Even splitting the nomogram into three ranges effects only a moderate and inadequate improvement.

A more satisfactory means of making the estimation of *M* (and *H*) fairly simple but accurate may be achieved by use of a slide rule. One suitable method is for the value of 0.247 PL to be marked off logarithmically for values of PL between about 60 and 500 along one scale of the rule. The second main scale of the rule would have values of PH^2 also marked logarithmically. The value of the maturity ratio *M* may be read off directly from a third logarithmically scaled range.

Two 'home-made' slide rules of card have been made.

In using the first the arrow pointer on the slide scale is set to the value of PL. The value of the maturity ratio *M* is read off on the bottom scale as the value corresponding to PH on the sliding scale.

Similarly in using the second rule set the arrow pointer on the slide to PH marked on the upper scale. The value of *H* is read off the lower scale opposite the corresponding value of PL on the sliding scale.

Note: If the method and instrument were developed a circular form of slide rule would be more compact and also give a more open scaling with consequent better reading accuracy.

Possibly still better would be to compute the full range of double-entry tables whereby for given values of PL and PH the corresponding values of *M* (and also of *H*) could be read directly in the body of the table.

The next two pages illustrate such a table, and give values of *M* for values of PL from 200-238 with PH covering the full range of values encountered in practice.

Estimate of maturity ratio *M* for values of PL and PH

Tabulated values of ratio x 1000, thus 1169 = 1.169

PH	Values of PL from 200 to 220										
	200	202	204	206	208	210	212	214	216	218	220
128	1169										
130	1134	1158	1182								
132	1100	1123	1147								
134	1067	1090	1113	1136	1160						
136	1036	1058	1080	1103	1126	1149	1172				
138	1006	1028	1049	1071	1094	1116	1139	1162			
140	978	998	1020	1041	1062	1084	1106	1129	1151	1174	
142	950	970	991	1012	1033	1054	1075	1097	1119	1141	1164
144	924	944	964	984	1004	1025	1046	1067	1088	1110	1131
146	899	918	937	957	977	997	1017	1038	1059	1079	1101
148	875	893	912	931	951	970	990	1010	1030	1050	1071
150	852	870	888	907	926	945	964	983	1003	1023	1043
152	829	847	865	883	901	920	939	958	977	996	1015
154	808	825	843	860	878	896	914	933	951	970	989
156	787	804	821	838	856	873	891	909	927	946	964
158	767	784	800	817	834	851	869	886	904	922	940
160	748	764	781	797	813	830	847	864	881	899	916
162	730	746	761	777	794	810	826	843	860	877	894
164	712	728	743	759	774	790	806	823	839	856	872
166	695	710	725	740	756	771	787	803	819	835	851
168	679	693	708	723	738	753	768	784	799	815	831
170		677	691	706	721	735	750	765	781	796	812
172			675	690	704	718	733	748	763	778	793
174				674	688	702	716	731	745	760	775
176					672	686	700	714	728	743	757
178						671	684	698	712	726	740
180							669	683	696	710	724
182								668	681	695	708
184									666	680	693

Estimate of maturity ratio *M* for values of PL and PH

Tabulated values of ratio x 1000, thus 1164 = 1.164

PH	Values of PL from 220 to 240										
	220	222	224	226	228	230	232	234	236	238	240
140											
142	1164										
144	1131	1153	1176								
146	1101	1122	1144	1165							
148	1071	1092	1113	1134	1156	1177					
150	1043	1063	1083	1104	1125	1146	1167				
152	1015	1035	1055	1075	1096	1116	1137	1158	1179		
154	989	1008	1028	1047	1067	1087	1107	1128	1148	1169	
156	964	983	1002	1021	1040	1060	1079	1099	1119	1139	1160
158	940	958	976	995	1014	1033	1052	1071	1091	1111	1131
160	916	934	952	970	989	1007	1026	1045	1064	1083	1103
162	894	911	929	947	964	983	1001	1019	1038	1057	1076
164	872	889	906	924	941	959	976	994	1013	1031	1049
166	851	868	885	901	919	936	953	971	988	1006	1024
168	831	847	864	880	897	914	931	948	965	982	1000
170	812	828	843	860	876	892	909	926	942	959	977
172	793	808	824	840	856	872	888	904	921	937	954
174	775	790	805	821	836	852	867	883	900	916	932
176	757	772	787	802	817	832	848	863	879	895	911
178	740	755	769	784	799	814	829	844	860	875	891
180	724	738	752	767	781	796	811	826	841	856	871
182	708	722	736	750	764	778	793	807	822	837	852
184	693	706	720	734	748	762	776	790	804	819	834
186	678	691	705	718	732	745	759	773	787	801	816
188		677	690	703	716	730	743	757	771	785	799
190			675	688	701	714	728	741	754	768	782
192				674	687	699	712	726	739	752	766
194					673	685	698	711	724	737	750
196						671	684	696	709	722	735
198							670	682	695	707	720
200								669	681	693	706
202									667	680	692

Additional details of the statistical analysis forming the basis of the calibration of the first prototype instrument.

Expansion of item (c) Complex Treatment

Note: All the data are available in the laboratory, on original test sheets and the various lengthy computations summarized in the blue ring binder "Details and Calibration of first prototype instrument 1972"

Prediction of maturity ratio *M*

The Phase I work indicated that the prediction of fibre maturity ratio would sensibly be given by

$$M = a \,.\, PL^n \,.\, (PL / PH)^m$$

A trial and error process was conducted to find the values of the parameters *n* and *m* which substantially minimized the standard error of the difference between airflow estimates of *M* yielded by the formula and the test values of PL and PH and the direct stapling determinations of *M*. This yielded the following tabulated values for the standard error (expressed as a percentage of the mean *M*) for the various combinations of *m* and *n*.

m =	$1\,{}^3/_4$	2	$2\,{}^1/_4$	$2\,{}^1/_2$
n = 0		5.9		
$^1/_{16}$		4.3		
$^1/_8$	4.2	3.7	3.9	
$^3/_{16}$		4.7		4.0

Rounding off to keep a fairly simple type of exponent (n.b. above values chosen being easy to manipulate on a desk computer) there is little point in fixing values of the parameters more accurately than

$$n = 1/8 \qquad m = 2$$

for effectively minimizing the percentage standard error. The constant *a* in the equation is of course chosen to give equal average values over the 100 cottons for the direct and the predicted values of *M*. This gives the final equation

$$M = 0.247 \,.\, PL^{1/8} \,.\, (PL / PH)^2$$

Prediction of Linear Density *H* (in millitex or 10^{-8} g/cm)

The general equation investigated was

$$H = b / PL \,.\, (PH / PL)^q$$

Again a range of values of the parameter *q* was tried to find the one which minimised the percentage standard error of the difference between predicted and directly measured values. The following was obtained.

q	2	$1\,^{7}/_{8}$	$1\,^{3}/_{4}$	$1\,^{5}/_{8}$	$1\,^{1}/_{2}$
% SE	4.2	3.9	3.7	3.8	4.1

With little appreciable loss in accuracy this gave

$$H = 60000 / PL \,.\, (PH / PL)^{1\,3/4}$$

Prediction of the Standard Fibre Weight per cm

The estimate of the standard fibre weight per cm *Hs* may be obtained by dividing the airflow estimate of *H* by the airflow estimate of *M*. Naturally because these latter two quantities are but estimates, and are both subject to real variation over and above the usual sampling and testing errors, the estimates of standard fibre weight per cm are still more inaccurate, useful for crude selection purposes but too high to permit accurate selection for many breeding purposes.

Taking the predicted values yielded for and *M* and *H* by the two formulae

$$\text{predicted } M = 0.247 \,.\, PL^{1/8} \,.\, (PL / PH)^{2}$$

$$\text{predicted } H = 60{,}000 / PL \,.\, (PH / PL)^{1\,3/4}$$

$$\text{predicted } Hs = \text{predicted } H / \text{predicted } M$$

determinations were made of the percentage standard deviation of differences between predicted *Hs* obtained from the airflow results and the usual estimates of *Hs* determined by the ratio

(direct test value of H) / (direct test value of M)

Calculation yielded the value of standard error = 6.0% which compares with 3.7% for the differences between predicted and test values of *M* and also 3.7% for the standard error of differences between airflow predictions of *H* and actual test values of *H*.

General description of instrument and method of operation

The instrument is a double compression airflow device. Measurements are made of the air permeability of test specimens packed into a container, first at a low compression and then again after compressing to a higher density. The permeability is given in terms of the pressure difference across the specimen corresponding to a fixed rate of flow (the fixed rate at the initial compression is higher than the fixed rate at the higher compression).

The effect of cotton fibre maturity and linear density on the air permeability is not the same at both compressions. Ignoring the effects of variation in other fibre features which are of much smaller magnitude, a statistical calibration of the instrument enables estimates to be made of fibre maturity ratio and fibre average linear density from the two pressure readings.

It should be noted that these results are estimates: they are not direct measurements of the two quantities concerned, namely maturity and linear density. However the closeness of the statistical relations that have been established indicate that these airflow estimates of maturity and linear density are sufficiently accurate for use when it is desired to exert a selection pressure, to isolate material for purposes of cotton breeding or for approximate quality evaluation.

Test specimen

The laboratory sample should be representative of the main bulk. For convenience it should be of 10-20 g mass. The sample should be prepared by opening it to give homogeneous fibre-to-fibre

separation with substantially random orientation. Passing the sample through a miniature card and accumulating the web gives a suitable means of preparation. The use of some forms of fibre blender may be equally acceptable. If a Shirley Analyser is used care must be taken to ensure that the fibres do not lodge between the cage and the transparent cover (and tend to lie transverse to the direction of rotation of the cage) but fall continuously into the collecting chamber at the rear.

The mass of the specimen shall be 4.00 g.

Instrument

The specimen holder consists of a cylindrical chamber into which fits a holder top: the ends of the chamber and of the holder top are perforated. With the side lever in the vertical position and the holder top in place, the initial length of the specimen chamber is 34 mm, giving the initial relatively low compression (specimen density 0.1911 g/ml). The lever is pulled forward to the horizontal position, reducing the size of the chamber for high compression to a length of 17 mm (specimen density 0.3821 g/ml).

For low density of packing the initial constant rate of' flow is 4 l/min. When the lever is operated to give the high packing density a second flow controller operates, reducing the flow rate (checked with no specimen in holder) to 1 l/min.

Two pressure gauges are arranged on the front of the instrument. The left-hand gauge is used. for all pressures in the range 0-250 mm of water. If the pressure exceeds 250 mm the air stream is automatically switched to record the pressure on the right-hand gauge, marked from 0-500 mm but only used in the range 250-500 mm. The use of two gauges gives a more sensitive means of' measuring low pressures than is afforded by the use of the right-hand gauge only.

Adjustments and checks to the instrument before testing

a) Occasional

With the pump switched off and the specimen holder empty, check that both pressure gauges are reading zero (0 ± 0.1 mm). Adjustment of these gauges is made from the back of the instrument by inserting a screwdriver through the central hole in the gauge casing, first removing the small cover. Take great care to keep screwdriver perpendicular to the back of the gauge to prevent internal damage to the mechanism

Once set, it is rarely necessary to readjust the zero. For a small deviation from zero, the alternative is to correct each test reading by subtracting the reading at zero flow.

The glass front of the gauge may be tapped slightly before making any check reading.

b) Before each set of tests

This should be carried out before testing a series of specimens, especially at the start of the day. If the temperature of the laboratory changes during the night it is advisable to switch the motor on and turn right-hand switch to TEST so that air is drawn through the instrument to bring it into temperature equilibrium with the test atmosphere. This should not require more than 5-10 minutes. Carry out the following adjustment before testing the specimens.

i) Switch pump on (left-hand switch glows green).
Turn right-hand switch to TEST and check specimen holder is empty.
Check lever handle is in the upper position.
Adjust flowmeter reading to 4 l/min using left-hand red knob.

ii) Pull handle forward to lower position.
Adjust flowmeter reading to 1 1/min using right-hand knob.

If the instrument is in temperature equilibrium with the atmosphere these two adjusts should suffice for a test session during a day. If the instrument is used continuously check at least every three hours.

Test procedure

a) The motor may be left running throughout a series of tests.

b) Start with right-hand switch to LOAD; lever handle should be in upper position.

c) The weighed test specimen is packed into the holder about one-sixth at a time, pushing it down firmly with the forefinger to ensure even packing. Push the last two tufts in very firmly, so that bottom of the holder is heard to make contact with the end stop. The holder top is inserted, withdrawn to check that no fibres have been trapped and to assist fibre compression takes place evenly, re-inserted and turned to lock into position.

d) Turn right-hand switch to TEST.

Wait 5 - 10 seconds for equilibrium to be reached and take reading of the pressure (PL).

e) Lower the lever handle to the bottom position, wait 5-10 seconds for equilibrium and take reading of pressure at this higher compression (PH).

f) Immediately after taking second pressure reading

i) Raise handle to upper position.
ii) Remove holder top.
iii) Remove test specimen by switching to VENT to blow cotton out.
iv) Switch to LOAD for start of next pair of observations.

g) It is preferable to make a second pair of determinations, of PL and PH, on each test specimen.

Each of the six portions of the test specimen should. be taken in turn, and fluffed. into a much looser state resembling the original condition. Loosen the tuft, by pulling it several times like a concertina. Do not break the tuft into many small parts in order to loosen the fibres because this causes small clumps to occur instead of retaining the loose random fibre-to-fibre separation.

Follow the above procedure, (c) to(f), to obtain second measures of PL and PH.

Note: For pressures below 100 mm estimate readings to at least 0.5 mm.

Effect of condition of openness of sample

Because of the 1972 redundancies it was possible to make but a few experiments to check on the effect of the openness of the sample.

Tests were made on the prototype instrument by three people, each making determinations on two test specimens per sample, with as usual duplicate readings per specimen, withdrawing and replacing the specimen after the first.

Twenty samples were used and were tested.

a) in the form of card web.

b) after opening on the Shirley Analyser - but with no special precautions to avoid accumulation of the cotton between the cage and the cover.

c) as raw cotton.

A total of 20 out of the basic set of 100 was tested. The fibre test results by direct measurement were available. The following summarises the position.

Condition of sample	Average predicted maturity ratio *M*	Correlation coefficient with direct test values of *M*
Card web	0.90	r = 0.975
Analysed lint	0.87	r = 0.953
Raw cotton	0.71	r = 0.640
Average direct test value of M = 0.91		

The correlation coefficient for the card web samples is high as would be expected and the average predicted and average direct values for the selected 20 samples are close. For lint obtained by passage through the Shirley Analyser the relationship is not so close, but still good. The use of raw cotton should be avoided, as shown by the poor relationship. If the air current on the Shirley Analyser had been altered so that cotton did not accumulate and align itself partly sideways across the cage and below the transparent cover instead of falling directly and continuously into the rear collecting chamber it is probable that the results would have been virtually indistinguishable from those for card web. Other instruments of the fibre blender type do not give such alignment but are an approach to card web in their formation.

Appendix A

Detailed table of results, direct test values of fibre characteristics, airflow estimates of fibre characters, additional details of cottons used.

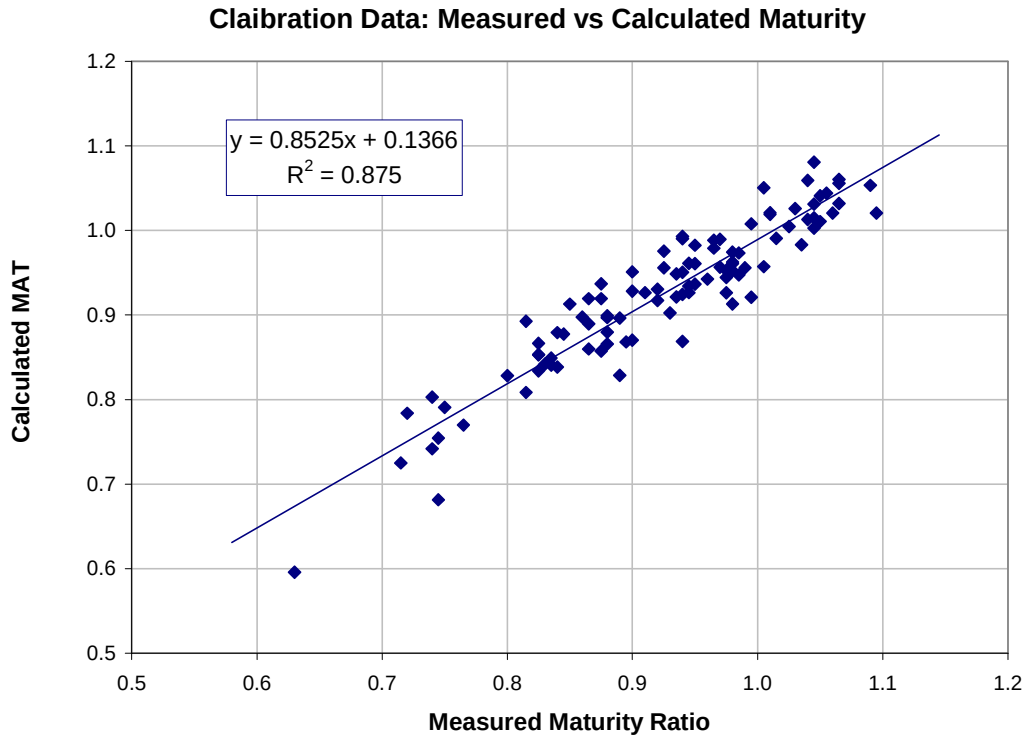
NB The original appendix also contains Shirley Institute Reference Numbers for the 100 cottons, identifying their storage locations in the old cellars. Since these buildings are long demolished and their contents scattered to the four winds, there seemed little point in including these data.

Phase 2 Calibration Data: Samples 1 to 50

	Variety/Origin	Test data		Airflow Estimates			Direct Measurements		
		PL	PH	M	H	Hs	M	H	Hs
1	Sudan Sakel	233.0	171.4	0.90	150	167	0.930	144	155
2	Bengals	83.4	54.1	1.02	337	331	1.060	340	321
3	Texas	211.1	158.1	0.86	171	199	0.865	167	193
4	Oomras	98.9	64.2	1.04	285	274	1.050	288	274
5	ICCS K1	84.0	53.9	1.04	329	315	1.055	329	312
6	Texas	173.9	126.3	0.89	197	221	0.815	199	244
7	Bengals	97.5	66.1	0.95	312	327	0.975	337	346
8	Sudan Lambert	187.0	130.0	0.98	170	173	1.035	166	160
9	Argentine	274.6	225.1	0.74	154	208	0.740	164	222
10	ICCS E1	344.2	274.1	0.81	117	145	0.815	109	134
11	Texas	191.8	143.7	0.85	189	222	0.835	198	237
12	Iran	199.0	146.8	0.88	177	201	0.880	180	205
13	Sudan American	139.4	91.8	1.06	207	196	1.065	203	191
14	Texas	127.9	86.5	0.99	237	239	0.940	239	254
15	Bengals	92.1	61.9	0.96	325	338	0.980	323	330
16	Texas	169.1	120.8	0.92	197	214	0.865	181	209
17	Uganda	286.3	233.3	0.75	146	194	0.745	148	199
18	Sudan sakel	231.6	166.2	0.95	145	153	0.985	140	142
19	St. Vincent S.I.	398.9	309.8	0.87	97	112	0.880	99	113
20	Sudan American	159.3	108.0	1.01	191	188	1.040	198	190
21	Uganda	240.9	184.7	0.83	156	188	0.825	153	185
22	Oomras	102.1	67.4	1.01	284	281	1.050	282	269
23	Uganda	276.4	212.9	0.84	137	164	0.835	135	162
24	Texas	227.7	186.6	0.72	186	257	0.715	170	238
25	Lankart	263.2	224.5	0.68	173	253	0.745	163	219
26	ICCS G1	399.7	374.3	0.60	134	225	0.630	137	217
27	Sudan Sakel	116.0	78.0	0.99	258	261	0.970	261	269
28	Tipperah	66.9	42.8	1.02	410	402	1.095	395	361
29	Bengals	105.5	75.3	0.87	315	363	0.895	305	341
30	ICCS I1	152.9	111.8	0.87	227	262	0.825	223	270
31	Sudan Sakel	233.7	169.7	0.93	147	158	0.945	143	151
32	Karnak	243.4	177.2	0.93	141	153	0.975	135	138
33	Ashmouni	177.6	126.9	0.92	188	203	0.940	183	195
34	Memphis	187.3	134.0	0.93	178	192	0.900	183	203
35	Texas	189.7	141.7	0.85	190	223	0.825	193	234
36	Karnak	232.9	170.3	0.91	149	163	0.980	137	140
37	Texas	190.4	137.5	0.91	178	195	0.850	171	201
38	Uganda	271.7	210.6	0.83	141	171	0.800	136	170
39	Ashmouni	222.6	167.5	0.86	164	191	0.875	173	198
40	Mexicala	213.0	158.0	0.88	167	190	0.845	164	194
41	Peru Tanguis	172.4	123.3	0.92	194	211	0.875	194	222
42	Texas	159.2	111.1	0.96	201	210	0.925	203	219
43	Memphis	211.3	157.3	0.87	169	195	0.900	172	191
44	Memphis	167.4	117.5	0.95	193	203	0.900	196	218
45	Sudan American	296.7	236.7	0.79	136	172	0.750	147	196
46	Russian	157.1	104.5	1.05	187	178	1.005	187	186
47	Karnak	233.1	166.5	0.96	143	149	1.005	141	140
48	Ashmouni	175.2	122.7	0.96	184	191	0.950	190	200
49	Oomras	101.1	64.5	1.08	270	250	1.045	272	260
50	Bengals	83.1	54.7	0.99	347	351	1.015	357	352

Phase 2 Calibration Data: Samples 51 to 100

	Variety/Origin	Test data		Airflow Estimates			Direct Measurements		
		PL	PH	M	H	Hs	M	H	Hs
51	Montserrat S.I.	261.4	197.4	0.87	140	162	0.940	136	145
52	Turkey	241.1	184.0	0.84	155	184	0.830	156	188
53	Bengals	74.6	47.3	1.05	362	344	1.090	353	324
54	Sudan American	290.9	230.0	0.80	137	170	0.740	145	196
55	Uganda BC66	365.4	299.3	0.77	116	150	0.765	120	157
56	Peru Tanguis	160.2	113.0	0.94	203	217	0.950	205	216
57	Peru Tanguis	165.3	117.8	0.92	201	218	0.995	194	195
58	Nigerian Ishan	122.5	84.7	0.94	257	272	0.960	255	266
59	Texas	135.3	92.2	0.98	227	231	0.950	224	236
60	Texas	155.0	106.2	0.99	200	202	0.965	202	209
61	Cal. Acala 4-42	176.5	124.2	0.95	184	193	0.980	195	199
62	Montserrat S.I.	283.0	219.9	0.83	136	165	0.890	140	157
63	Oomras	100.0	64.4	1.06	278	262	1.040	283	272
64	Bengals	91.0	60.6	0.98	324	331	0.965	326	338
65	Bengals	93.2	62.3	0.97	318	326	0.980	336	343
66	Bengals	93.6	63.2	0.96	322	337	0.990	327	330
67	Sudan American	152.7	102.6	1.03	196	191	1.030	191	185
68	Sudan American	158.5	107.1	1.02	191	187	1.010	190	188
69	Sudan American	162.6	112.6	0.97	194	199	0.985	200	203
70	Cal. Acala 4-42	229.3	180.8	0.78	173	220	0.720	162	225
71	Sudan Sakel	276.3	205.8	0.90	130	144	0.880	127	144
72	Texas	169.7	120.1	0.94	193	206	0.875	195	223
73	Guatemala	204.6	149.7	0.90	170	189	0.860	181	210
74	Guatemala	191.3	140.0	0.89	182	204	0.865	173	200
75	Peru Tanguis	146.8	103.1	0.93	220	236	0.945	213	225
76	Peru Tanguis	168.2	117.5	0.96	190	198	0.980	188	192
77	Guatemala	218.5	164.6	0.85	167	196	0.825	177	215
78	Giza 30	218.0	155.1	0.96	152	159	0.970	148	153
79	Texas	191.1	139.3	0.90	181	201	0.890	193	217
80	Uganda BP52	269.9	203.0	0.88	135	154	0.840	150	179
81	Hopi Acala	153.1	101.2	1.06	190	179	1.065	190	178
82	Sudan Sakel	300.3	225.1	0.90	121	135	0.880	126	143
83	Sudan BAR 14/25	222.2	154.2	1.01	142	141	0.995	136	137
84	Sudan Sakel	272.8	200.0	0.93	128	138	0.910	127	140
85	Sudan Lambert	194.9	134.5	1.00	161	160	1.045	149	143
86	Sudan Sakel	220.6	156.7	0.96	149	156	0.945	149	158
87	Sudan Albar	155.5	104.3	1.03	192	186	1.065	193	181
88	Sudan Albar	155.6	104.4	1.03	192	186	1.045	191	183
89	Sudan Sakel	234.9	171.1	0.92	147	159	0.935	147	157
90	ICCS A1	133.2	91.0	0.98	231	237	0.925	219	237
91	ICCS A2	136.4	92.5	0.99	223	225	0.940	225	239
92	ICCS A4	135.2	91.1	1.00	222	221	1.025	213	208
93	ICCS B1	173.1	121.9	0.95	188	198	0.935	184	197
94	ICCS B2	172.2	121.1	0.95	188	198	0.940	190	202
95	ICCS B3	174.3	124.0	0.93	190	204	0.920	180	196
96	ICCS C1	256.0	187.9	0.92	136	149	0.920	143	155
97	ICCS C2	244.2	186.9	0.84	154	184	0.840	159	189
98	ICCS D1	228.1	163.8	0.94	147	156	0.975	136	139
99	ICCS F1	90.5	59.0	1.02	314	307	1.010	320	317
100	ICCS H1	113.7	75.4	1.01	257	253	1.045	255	244


Claibration Data: Measured vs Calculated Maturity
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R2 = 0.875
Calculated MAT
Measured Maturity Ratio
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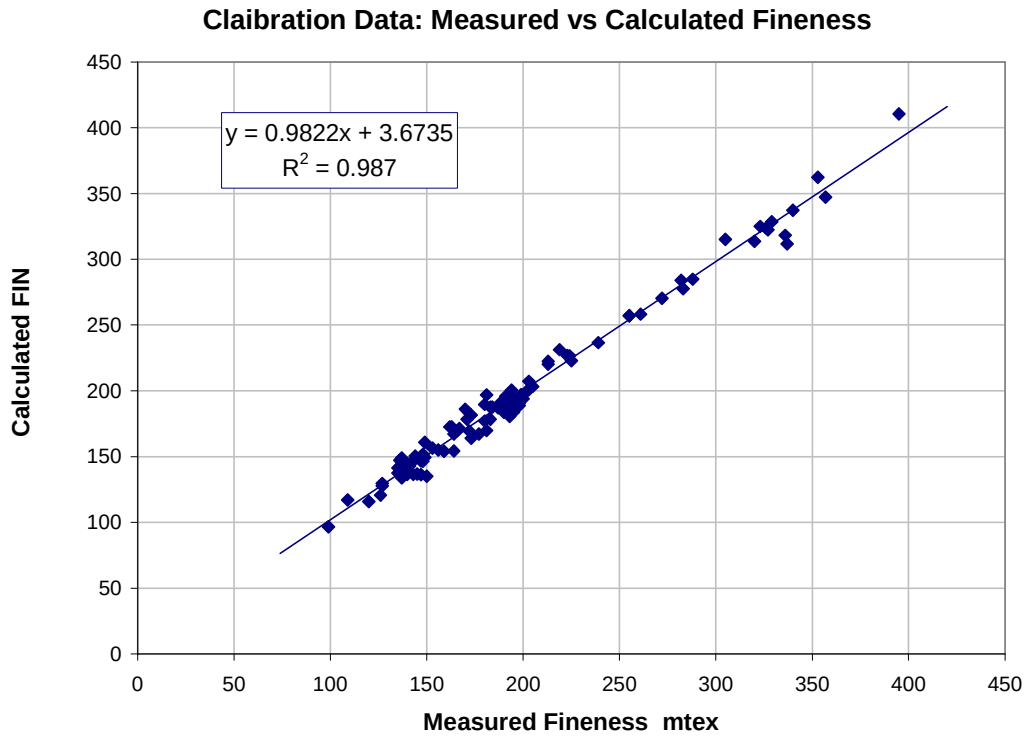
1.0
0.9
0.8
0.7
0.6
0.5
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2


Claibration Data: Measured vs Calculated Fineness
y = 0.9822x + 3.6735
R2 = 0.987
Calculated FIN
Measured Fineness mtex
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450

Appendix B

Comparison of first and second prototype models of double compression airflow maturity / Fineness tester

Following the return of the first instrument from Courtaulds in December 1972 it became possible to make a direct comparison of it with the second instrument. With the heavy reduction in staff and the overload of CRC and other work it was necessary to carry out the comparison personally. It had been agreed with Mr. Burkitt and Mr. Miles of IIC that at this stage it would be sufficient to make direct tests on specimens measured on both machines in turn.

A second purpose, one which governed the choice of the test material, was to determine whether the original machine gave estimates of Micronaire value in agreement with those obtained originally. Courtaulds reported a difference, but this might possibly be due to the variation in the setting of their Micronaire instrument.

These purposes were considered jointly by making tests on the 15 samples in the full set of 100 and representing International Calibration Cotton Standards.

Two specimens of each standard were taken. One specimen was tested for PL and PH on the original machine (No. 1), the specimen was removed and tested on machine 2 (i.e. the new untried instrument). This procedure was repeated, testing a second time on machine 1 followed by a second time on machine 2. The other specimen of each standard was tested similarly, except the test was made on machine 2 first and machine 1 second.

Because of other work in hand it was not possible to make the machine comparison until the week commencing February 12.

In this necessarily brief trial confined to three days it is established:

1. The second machine gives values of pressure just about 1% higher than those of the original machine. The effect is not of any great importance on estimates of maturity which depend largely upon the ratio of the two pressures.
2. The estimates of Micronaire value obtained from the lower (initial) compression by the fourth operator (E.L.) differ from those obtained as the average of the three operators in the main trial by only small amounts.

Average of first three operators on machine 1	4.80
Average for fourth operator machine 1	4.82
Average for fourth operator machine 2	4.78

Difference between original instrument (No. 1) and second (No. 2)

Averages of 2 determinations on each of 2 specimens for both machines

15 selected samples of ICC Standards

Sample	ICCS	Machine 1		Machine 2	
		PL	PH	PL	PH
5	K1	81.4	52.2	83.7	53.8
10	E1	336.3	259.3	341.2	262.8
26	G1	396.8	366.8	399.8	362.8
30	I1	152.2	109.5	154.5	111.8
90	A1	135.0	91.7	136.8	93.7
91	A2	137.0	92.3	139.8	94.7
92	A4	135.5	90.4	137.2	92.1
93	B1	175.3	123.2	178.0	126.2
94	B2	170.0	118.5	172.8	121.8
95	B3	175.0	122.8	175.0	124.8
96	C1	252.5	184.0	252.5	185.5
97	C2	237.8	178.8	239.8	179.0
98	D1	226.8	160.5	227.0	161.2
99	F1	90.2	57.9	92.0	60.6
100	H1	112.8	74.4	113.0	75.9
Means		**187.6**	**138.8**	**189.5**	**140.4**
Machine 2 / Machine 1				**1.010**	**1.012**
PL / PH		**1.352**		**1.350**	

The second machine gives measured pressures at low and high packing densities (PL and PH) that are around 1% higher than those of the first machine.

Cause of small differences between instruments

Two instruments could give different values of PL and PH if:

a) The length of the specimen holder was not the same for both instruments at both compressions. If one length differed then pressure differences noted on the gauges would differ at that particular compression - equally at initial and higher compression the length of the holder was different for both instruments, thus giving errors of different amount, possibly in different directions.

b) Any difference in specimen holder diameter would cause two instruments to give readings

of PL and PH differing in the same direction.

c) The flowmeter tube markings of 4 and 1 litres/min could be incorrect. *Note* any instruments should have the marks checked against one "master flowmeter", possibly to the extent that the marks were added at this stage. The manufacturer's calibration could easily be out by 1 - 2% and consequently cannot be relied upon.

d) The valves controlling the flows to nominally constant values might be variable in their performance between running under no resistance and with a resistance in the circuit. To some extent this may be checked by noting the variation in the small pressure drop between pressure gauge with and without air flowing through the system but without anything in the specimen holders.

Two forms of check were made (the instrument section had previously checked the pressure gauge of instrument 2 and found it to be OK - we had earlier made a check on the pressure gauges of instrument 1 and found them well within manufacturer's tolerances).

A. Specimen holder connected directly to an independent rotameter flowmeter. Instrument flows adjusted to give in turn 4 and 1 litre/min. *N.B.* connection direct so that there is no appreciable resistance, the independent flowmeter taking air at atmospheric pressure.

Marked flow rate on machines	Independent flowmeter reading (litres /hour)		
	Machine 1	Machine 2	Mach 2 / Mach 1
4 litres/min	230.5	230.5	1.000
1 litre/min	55.5	56.0	1.009

B. Flows adjusted for 1 and 4 l/min under usual 'Test' conditions without any specimen or other resistance in holder. Various tubes packed with nylon fibres to give several resistances were available, the tubes being each in a rubber bung to fit tightly into a specimen older. This method gives measures of pressure drop at constant flow independent of the size of the holder. Determinations of P (mm).

At 4 litres/min				At 1 litre/min			
	Mach 1	Mach 2	M2/M1		Mach 1	Mach 2	M2/M1
a)	58.8	60.0	1.020	g)	134.8	135.6	1.006
b)	84	85.0	1.012	h)	100.8	102.2	1.014
c)	114	115	1.009	i)	52.8	53.8	1.019
d)	181	182	1.006	j)	166.4	168.0	1.010
e)	237	239	1.008				
f)	417	420	1.007				
Means			**1.010**				**1.012**

N.B. Holders packed with fibres are better than short lengths of capillary tubing which in this range of flows commonly give non-laminar flow.

Conclusions

1. For the flow fixed at the higher compression condition of 1 litre/min Machine 2 gives values of recorded pressure differences that are about 1% higher

    a) when the same rate of flow of air is maintained and tests are made on cottons in the usual way,

    b) when the holder is not packed but a plug is inserted to give a resistance.

    Moreover when both machines have their flowmeters adjusted to give constant nominal rates (of 1 l/min) the actual flows measured on an independent flowmeter shows that Machine 2 is passing about 1% more air than Machine 1.

    Clearly in this case the marking of 1 litre/min on the rotameter of Machine 2 is incorrect relative to that of Machine 1.

2 At 4 litres/min nominal both machines register the same amount of air passing through the independent rotameter: the markings as indicated therefore are in agreement (even if not accurate absolutely).

    However

    a) Machine 2 gives results on cotton specimens that are 1% higher than those obtained using Machine 1.

    b) With plugs inserted instead of cotton specimens Machine 2 gives results 1% on the high side.

The sole cause of the difference is certainly not a difference in holder dimensions. It could arise from the operation of more than one factor, however, including mode of operation of the flostat controlling this higher flow. The pressure gauge is unlikely because it has been checked - but there is always the possibility of an alteration having happened during assembly of Instrument 2 (the check on the gauge of Instrument 1 was made with the gauge in situ, by suitable disconnections of tubes to give a means of connecting with the independent water-pressure gauge).

Predictions of Micronaire Value from Pressure Difference PL

(measured at initial compression)

		Predicted			ICCS	Difference (Mx - Ms)		
Sample	**ICCS**	**M 72**	**M1 73**	**M2 73**	**Ms**	**M 72**	**M1 73**	**M2 73**
5	K1	7.45	7.59	7.47	7.40	+0.05	+0.18	+0.07
10	E1	2.81	2.86	2.83	2.83	-0.02	+0.03	0
26	G1	2.53	2.55	2.53	2.61	-0.08	-0.06	-0.08
30	I1	5.01	5.02	4.97	2.91	+0.10	+0.11	+0.06
90	A1	5.51	5.46	5.41	5.50	+0.01	-0.04	-0.09
91	A2	5.42	5.40	5.33	5.54	-0.12	-0.14	-0.22
92	A4	5.45	5.44	5.40	5.51	-0.06	-0.07	-0.11
93	B1	4.59	4.55	4.50	4.60	-0.01	-0.05	-0.10
94	B2	4.61	4.65	4.60	4.63	-0.02	+0.02	-0.04
95	B3	4.57	4.56	4.55	4.46	+0.11	+0.09	+0.09
96	C1	3.47	3.51	3.51	3.41	+0.06	+0.10	+0.10
97	C2	3.59	3.66	3.64	3.51	+0.08	+0.15	+0.13
98	D1	3.77	3.79	3.78	3.74	+0.03	+0.05	+0.04
99	F1	7.11	7.13	7.04	7.08	+0.03	+0.05	-0.04
100	H1	6.13	6.16	6.16	6.22	-0.09	-0.06	-0.06
Average		**4.80**	**4.82**	**4.78**	**4.66**			

M 72 Micronaire values predicted from initial pressure readings PL in the main calibration of Machine 1

M1 73 Micronaire values predicted for Machine 1 in this comparison trial

M2 73 Micronaire values predicted for Machine 2 in this comparison trial

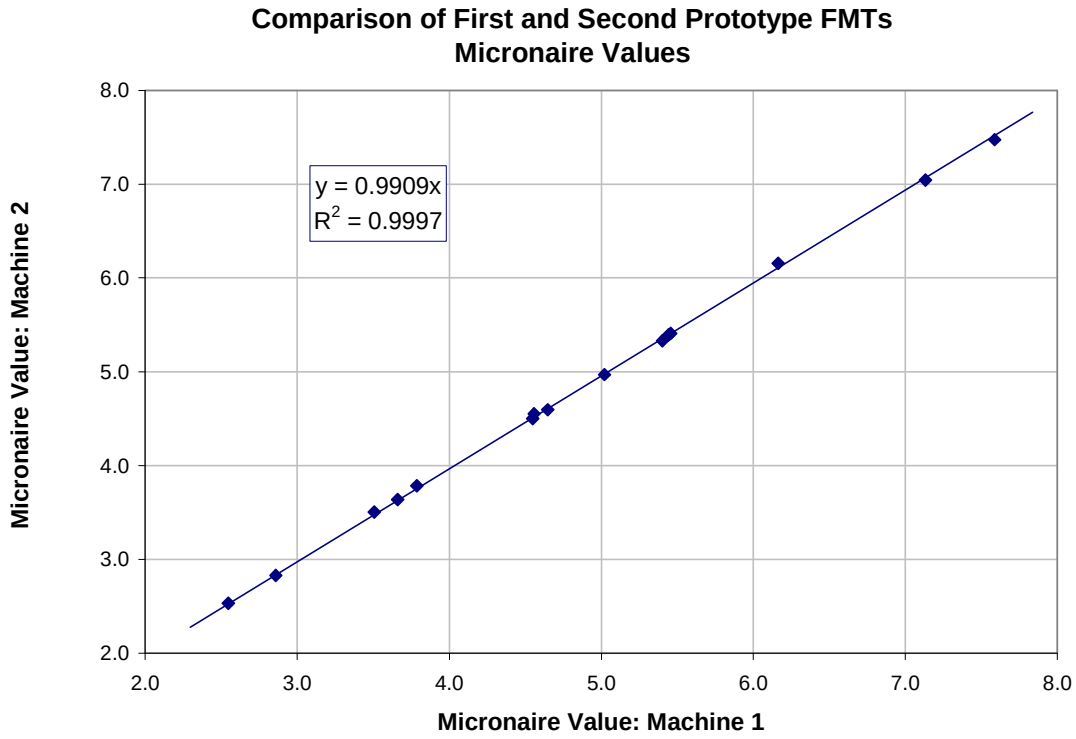
Ms International Calibration Cotton Standard values

Predictions made using the previously established empirical relation

$$Micronaire\ value = 0.60 + 850 / (PL + 40)$$

The original estimates of Micronaire value (M 72) were obtained from the determinations made in duplicate by three operators. The repeat determinations giving estimates of Micronaire value on the original instrument (M1 73) and the new second instrument (M2 73) are obtained from the test results of one operator (also duplicate specimens) only.

The average values for the three sets of predictions range from 4.78 to 4.82 only. This agreement is well within any national and international tolerances for instruments giving Micronaire value.


Comparison of First and Second Prototype FMTs
Micronaire Values
y = 0.9909x
R2 = 0.9997
Micronaire Value: Machine 2
Micronaire Value: Machine 1
8.0
7.0
6.0
5.0
4.0
3.0
2.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0

PL & PH test data recorded by E. Lord, Micronaire values recalculated

Two test specimens per sample (a) and (b)
Specimen (a) begins with Machine 1; Specimen (b) begins with Machine 2

Sample		M 72 PL	M 72 PH	M 72 Mic	M1 73 PL	M1 73 PH	M1 73 Mic	M2 73 PL	M2 73 PH	M2 73 Mic
5	a1				82.0	52.0		83.8	53.8	
ICCS K1	a2				81.2	52.2		82.8	53.8	
	b1				81.2	52.2		84.0	53.8	
	b2				82.2	52.4		84.0	53.8	
	Mean	84.0	53.9	7.45	81.7	52.2	7.59	83.7	53.8	7.47
10	a1				340.0	256.0		340.0	257.0	
ICCS E1	a2				333.0	255.0		340.0	259.0	
	b1				334.0	261.0		341.0	266.0	
	b2				338.0	265.0		344.0	269.0	
	Mean	344.2	274.1	2.81	336.3	259.3	2.86	341.3	262.8	2.83
26	a1				415.0	383.0		418.0	383.0	
ICCS G1	a2				417.0	394.0		413.0	384.0	
	b1				380.0	346.0		389.0	344.0	
	b2				375.0	344.0		379.0	340.0	
	Mean	399.7	374.3	2.53	396.8	366.8	2.55	399.8	362.8	2.53
30	a1				152.0	108.0		155.0	111.0	
ICCS I1	a2				152.0	109.0		151.0	112.0	
	b1				154.0	111.0		154.0	111.0	
	b2				151.0	110.0		158.0	113.0	
	Mean	152.9	111.0	5.01	152.3	109.5	5.02	154.5	111.8	4.97
90	a1				134.0	91.2		136.0	93.8	
ICCS A1	a2				133.0	91.0		138.0	93.8	
	b1				135.0	90.8		136.0	93.2	
	b2				138.0	93.8		137.0	93.8	
	Mean	133.2	91.0	5.51	135.0	91.7	5.46	136.8	93.7	5.41
91	a1				135.0	92.8		140.0	94.4	
ICCS A2	a2				135.0	90.2		139.0	94.8	
	b1				138.0	92.4		140.0	93.6	
	b2				140.0	93.8		140.0	96.0	
	Mean	136.4	92.5	5.42	137.0	92.3	5.40	139.8	94.7	5.33
92	a1				137.0	89.0		139.0	91.0	
A4	a2				136.0	90.4		136.0	92.6	
	b1				135.0	91.0		136.0	91.8	
	b2				134.0	91.0		138.0	93.0	
	Mean	135.2	91.1	5.45	135.5	90.4	5.44	137.3	92.1	5.40

Sample		M 72 PL	M 72 PH	M 72 Mic	M1 73 PL	M1 73 PH	M1 73 Mic	M2 73 PL	M2 73 PH	M2 73 Mic
93	a1				178.0	124.0		181.0	128.0	
ICCS B1	a2				177.0	123.0		180.0	129.0	
	b1				170.0	122.0		175.0	123.0	
	b2				176.0	124.0		176.0	125.0	
	Mean	173.1	121.9	4.59	175.3	123.3	4.55	178.0	126.3	4.50
94	a1				169.0	118.0		173.0	122.0	
ICCS B2	a2				171.0	119.0		175.0	123.0	
	b1				170.0	118.0		171.0	121.0	
	b2				170.0	119.0		172.0	121.0	
	Mean	172.2	121.1	4.61	170.0	118.5	4.65	172.8	121.8	4.60
95	a1				177.0	122.0		175.0	126.0	
ICCS B3	a2				174.0	125.0		174.0	123.0	
	b1				173.0	121.0		176.0	126.0	
	b2				175.0	123.0		175.0	124.0	
	Mean	174.3	124.0	4.57	174.8	122.8	4.56	175.0	124.8	4.55
96	a1				250.0	180.0		247.0	181.0	
ICCS C1	a2				252.0	183.0		251.0	183.0	
	b1				256.0	187.0		255.0	189.0	
	b2				252.0	186.0		257.0	189.0	
	Mean	256.1	187.9	3.47	252.5	184.0	3.51	252.5	185.5	3.51
97	a1				238.0	178.0		239.0	180.0	
ICCS C2	a2				239.0	179.0		236.0	176.0	
	b1				237.0	178.0		239.0	179.0	
	b2				237.0	180.0		245.0	181.0	
	Mean	244.2	186.9	3.59	237.8	178.8	3.66	239.8	179.0	3.64
98	a1				229.0	163.0		229.0	164.0	
ICCS D1	a2				232.0	164.0		226.0	164.0	
	b1				222.0	156.0		226.0	160.0	
	b2				224.0	159.0		227.0	157.0	
	Mean	228.1	163.8	3.77	226.8	160.5	3.79	227.0	161.3	3.78
99	a1				90.2	57.2		91.0	59.8	
ICCS F1	a2				88.0	55.4		91.0	60.2	
	b1				91.2	58.8		93.8	62.0	
	b2				91.2	60.0		92.0	60.2	
	Mean	90.5	59.0	7.11	90.2	57.9	7.13	92.0	60.6	7.04
100	a1				112.0	72.4		113.0	74.4	
ICCS H1	a2				112.0	73.0		113.0	75.2	
	b1				113.0	76.6		113.0	76.8	
	b2				114.0	75.6		113.0	77.0	
	Mean	113.7	75.4	6.13	112.8	74.4	6.16	113.0	75.9	6.16