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The Effect of Variation of Air Density and Temperature on the Airflow Characteristics of Porous Fabrics

By

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ROYAL AIRCRAFT ESTABLISHMENT

The Effect of Variation of Air Density and Temperature on the Airflow Characteristics of Porous Fabrics

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SUMMARY

This note describes a series of tests made at low air densities and temperatures and establishes that the airflow through porous fabrics obeys the laws of dynamic similarity.

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1 Introduction

The airflow characteristics of most of the porous fabrics now used in the manufacture of parachutes were examined during the Second World War by Brown and Holford (Ref.1) at normal ground temperatures and pressures. They concluded that the porosity of these fabrics, and also of a fine wire mesh and ribbon meshes, increased with increasing pressure difference across them (that is, that U is equal to $f(p)\sqrt{p}$ where $f(p)$ is an increasing function of p) and, further, that $\frac{U}{p^x}$ was independent of p , where x is a constant the value of which depended on whether the yarn was composed of artificial or natural fibres. A limited number of experiments were also made by Duncan (Ref.2). $\frac{U}{\sqrt{p}}$ was considered an increasing function of speed. This was accepted as a characteristic of all parachute fabrics.

Taylor and Davies (Ref.3) measured the aerodynamic forces on porous sheets including fabrics and found little variation due to Reynolds number over the ranges of their experiments.

Simmons and Cowdrey (Ref.4) also measured the aerodynamic forces on fine wire mesh screens and noted but did not examine a 'speed effect'.

This note records the results of an investigation into the effects of variation of air temperature and density on the airflow characteristics of porous fabrics widely used for the manufacture of parachutes and indicates how these illustrate a more general form of the conclusions reached in Refs.1 and 2.

A list of symbols is given in Appendix I.

2 Method

2.1 Apparatus

In order that the airflow through and pressure difference across the fabric test specimens could be varied and measured readily an instrument similar to the High Pressure Porosity Instrument described in Ref.5 was used. It differed in that, to avoid the variable heating effect of the blower on the air passing through the fabric test specimens, the direction of the airflow was reversed - a two stage exhauster driven by a five horsepower electric motor replaced the single stage blower of the standard instrument. This modification also enabled greater pressure difference to be obtained and thus extended the range of readings at low air densities. The manometer board and certain other ancillary components were rearranged in order that the instrument could be housed in the limited space available. The final assembly is illustrated in Fig.1. The measurements were made in the No.2 Cold and Decompression Chamber at Synehurst in order that the air density and temperature could be varied as required.

2.2 Fabric Test Specimens

Twelve types of fabrics widely used for the construction of parachutes and differing from each other in porosity, treatment and/or material were tested in order that any conclusions might have a general application to parachutes. Details of porosity, specification, etc. are given in Table I. Each specimen was approximately one yard square and marked in ten positions by 3 inch diameter circles in such a way that no warp or weft threads were common to any two positions. An airflow measurement at some particular pressure difference across a specimen was effected by taking the mean of ten readings made at the centres of each of the marked positions as described in Ref.5.

2.3 Measurements Made

The tests carried out can be divided into two series. In the first the effect of low air density was examined. The airflow through the twelve fabric test specimens was measured at various pressure differences and air densities corresponding to those at heights above sea level of 0 to 30,000 ft. in increments of 5000 ft. The air density was measured by a standard aircraft altimeter. Control of the temperature was difficult and it varied through a range of 0°C to 20°C. Relative humidity was not measured but was probably of the order of 90% to 100%.

In the second series the effect of low temperature was examined. The measurements were made in the same way as those of the first series except that they covered a temperature range of -50°C to 0°C and the air pressure was not varied from atmospheric. Although the operators wore fabric face masks there was a continual suspension of ice particles in the atmosphere of the chamber. This indicated that the relative humidity must have been of the order of 100%.

3 Results

Figs.3 - 14 give the results of the tests graphically. The reliability of the measurements made at temperatures below 0°C was seriously affected by the accumulation of ice particles in the interstices of the fabrics. It was also aggravated by the impaired efficiency of the instrument. The clamping head did not move freely, the 'Sorbo' rubber ring became hard, and ice accumulated in the exhauster causing the electric motor to be overloaded frequently.

3.1 Discussion of Results

It has been suggested that increasing the pressure difference across a fabric increases the area of the fabric interstices relative to the yarn and that this will produce a change in porosity characteristics. If this were the only effect we should expect the indicated airflow to be independent of air density (or pressure) for a given pressure difference across a fabric. Refs. 1 and 2 implicitly accept this explanation in their conclusions. Fig.2 shows however that the indicated airflow increases with increasing air pressure for a constant pressure difference across the fabric test specimens.

To attempt an interpretation of this phenomenon let us assume that distortion has no appreciable effect on the porosity characteristics of a fabric. We can then apply the laws of dynamic similarity to the airflow through the fabric obtaining the well known result that the nature of the flow and hence the porosity is dependent on the Reynolds number. Thus if U is the mean velocity of the airflow through a fabric when the pressure difference across it is $\frac{1}{2}\rho V^2$* then the relative porosity

$$\frac{U}{V} = \psi(R) \quad \text{where } R = \frac{\rho V \ell}{\eta} \qquad \ldots\ldots\ldots\ldots(1)$$

---

* This fictitious V is introduced in order that results may be more directly applicable to parachutes. If $\frac{1}{2}\rho V^2$ corresponds to the mean pressure difference across the fabric of a parachute canopy inflated in a relative airstream then the relative velocity of the airstream will approximate to V.

Appendix II shows how $\frac{U}{V}$ and $\frac{R}{\ell}$ may be expressed in terms of the quantities measured, that is, expressed as functions of air temperature and pressure and, as read from the porosity instrument, the airflow through and pressure difference across the fabric test specimens. All the constituent factors of R, except ℓ, were varied.

In Figs.3 - 14 $\frac{U}{V}$ has been plotted against $\log_e \frac{R}{\ell}$ for the twelve specimens. It can be seen that where the air temperature was greater than 0°C the measurements appear to obey the relationship (1). Further, over this range of the investigation, the relationship seems to be of the form

$$\frac{U}{V} = m \log cR \qquad \text{..........(2)}$$

where m and c are constants dependent on the characteristics of the fabric. Table I gives values of m and $\log_e c\ell$ for each of the specimens and the method by which they were derived from the measured quantities is outlined in Appendix II.

Where the air temperature was less than 0°C the value of $\frac{U}{V}$ was mostly less than and never greater than the value to be expected from the relationship (1). As the collection of ice particles in the fabric interstices was almost certain to effect a reduction in the value of this ratio the results in this series qualitatively support our assumption.

An examination of the results given in Ref.4 shows that the 'speed effect' on wire meshes also conforms to equation (2).

3.2 Generalisation of Previous Work

Suppose in relationship (1) that

$$\psi(R) = k_5 R^{2x-1} \qquad \text{..........(3)}$$

now

$$R = \frac{\rho V \ell}{\eta} = \left[2\rho p \left(\frac{\ell}{\eta}\right)^2\right]^{\frac{1}{2}} \qquad \text{..........(4)}$$

also

$$\frac{U}{V} = \frac{U}{(p/\frac{1}{2}\rho)^{\frac{1}{2}}} \qquad \text{..........(5)}$$

Thus combining (3), (4) and (5), (1) may be written as

$$\frac{U}{(p/\frac{1}{2}\rho)^{\frac{1}{2}}} = k_5 \left[2\rho p \left(\frac{\ell}{\eta}\right)^2\right]^{(x-\frac{1}{2})} \qquad \text{..........(6)}$$

or

$$\frac{U}{p^x} = k_5 \cdot 2^x \cdot \rho^{x-1} \left(\frac{\ell}{\eta}\right)^{2x-1}$$

Now Brown and Holford concluded (Ref. 1) that

$$\frac{U}{p^x} = k_6 \quad \text{where } k_6 \text{ is independent of } p$$

This will conform to (1) provided

$$k_6 = k_5 \, 2^x \rho^{x-1} \left(\frac{\ell}{\eta}\right)^{2x-1} \qquad \text{..........(7)}$$

Thus their relationship may be generalised as

$$\frac{U}{V} = k_5 R^y \quad \text{where } y = 2x - 1 \qquad \text{..........(8)}$$

(8) may be related to (2) by

$$y = \frac{1}{\log_e cR} \qquad \text{..........(9)}$$

$$k_5 = \frac{m}{yR^y} \qquad \text{.........(10)}$$

Over a narrow range of R for small values of y equation (8) approximates closely to equation (2) if the mean values of y and k_5 given by equations (9) and (10) are used.

4 Conclusions

The results indicate that the laws of dynamic similarity hold for parachute fabrics and suggest that over the range of the investigation they may be conveniently summarised by the expression

$$\frac{U}{V} = m \log cR$$

where m and c may be regarded as fabric characteristics.

4.1 Further Action

The relationship between $\psi(R)$ and the fabric parameters should be established analytically.

REFERENCES

No.	Author	Title, etc.
1	Brown and Holford	Porous properties of various materials liable to be used for making parachutes. Current Paper No. 24. March, 1949.
2	Duncan	The cause of the spontaneous opening and closing of parachutes (The phenomena of "Squidding"). R. & M. 2119. December, 1943.
3	Taylor and Davies	The aerodynamics of porous sheets. R. & M. 2237. April, 1944.
4	Simmons and Cowdrey	Measurements of the Aerodynamic forces acting on porous screens. R. & M. 2276. August, 1945.
5	Carling and Leigh	The design of a high pressure porosity instrument. Technical Note No. Aero. 1804. July, 1946.

APPENDIX I

List of Symbols

c		fabric constant
d		density of alcohol used for porosity instrument manometers
$f(p)$		function of p
$F(T)$		function of T
h		height of the pressure difference manometer of the porosity instrument
H		height of the flow reading manometer of the porosity instrument
k_1		a constant of the flow meter scale of the porosity instrument
k_2		a constant of the venturi of the porosity instrument
k_3	=	$\left(\frac{k_1}{k_2}\right)^{\frac{1}{2}} = 0.0151$
k_4		constant $= 2.23 \times 10^{12}$
k_5		fabric constant
k_6	=	$k_5\, 2^x \rho^{x-1} \left(\frac{\ell}{\eta}\right)^{2x-1}$
ℓ		some suitable linear dimension of a fabric
m		fabric constant
p		pressure difference across a fabric
P	=	$k_2 \left(\frac{1}{2}\rho_T U^2\right)$
R	=	$\frac{\rho V \ell}{\eta}$
T		temperature in $^{\circ}$A, used as a suffix to denote the value of a physical quantity at a temperature T
U		mean velocity of the airflow through a fabric when the pressure difference across it is p
U_i	=	$\left(\frac{H_T}{k_1}\right)^{\frac{1}{2}}$, $U_i = U$ when $T = 288$ and $\sigma = 1$
V	=	$\left(\frac{p}{\frac{1}{2}\rho}\right)^{\frac{1}{2}}$
x		fabric constant
y	=	$2x - 1$
η		viscosity of air

ρ	air density
σ	relative air density σ_{288} = relative air pressure in standard atmosphere
$\psi(R)$	function of R

APPENDIX II

Relationship between Basic and Measured Quantities

The following relationships are either implied or their derivation from basic data is obvious. The slug foot second system of units is used.

$$p = \tfrac{1}{2}\rho_T V^2 \qquad \ldots\ldots\ldots\ldots(1)$$

$$p = h_T d_T \qquad \ldots\ldots\ldots\ldots(2)$$

$$P = H_T\, d_T \qquad \ldots\ldots\ldots\ldots(3)$$

$$\sigma_T = \frac{288\,\sigma_{288}}{T} \qquad \ldots\ldots\ldots\ldots(4)$$

$$\eta_T = 0.0835\,\eta_{288}\,\frac{T^{3/2}}{T + 120} \qquad \ldots\ldots\ldots\ldots(5)$$

$$U_i^2 = \frac{H_T}{k_1}\,,\ U_i = U \text{ when } T = 288^{\circ}\text{A and } \sigma = 1 \qquad \ldots\ldots\ldots\ldots(6)$$

$$P = k_2\,(\tfrac{1}{2}\rho_T U^2) \qquad \ldots\ldots\ldots\ldots(7)$$

$$d_T = 1.64 \times 10^{-3}\,(1260 - T) \qquad \ldots\ldots\ldots\ldots(8)$$

From (1) and (7)

$$\frac{U}{V} = \left[\frac{\tfrac{1}{2}\rho_T}{p} \cdot \frac{P}{k_2 \tfrac{1}{2}\rho_T}\right]^{\frac{1}{2}}$$

$$= \left[\frac{P}{k_2 p}\right]^{\frac{1}{2}}$$

$$= \left[\frac{H_T\,d_T}{k_2\,h_T\,d_T}\right]^{\frac{1}{2}} \qquad \text{from (2) and (3)}$$

$$= \left[\frac{k_1\,U_i^2}{k_2\,h_T}\right]^{\frac{1}{2}} \qquad \text{from (6)}$$

$$\therefore \frac{U}{V} = k_3 \frac{U_i}{h_T^{\frac{1}{2}}} \quad \text{where } k_3 = \left(\frac{k_1}{k_2}\right)^{\frac{1}{2}} \qquad \ldots\ldots\ldots\ldots(9)$$

Also

$$\left(\frac{R}{\ell}\right)^2 = \left(\frac{\rho_T \; V}{\eta_T}\right)^2$$

$$= \frac{2\rho_T p}{\eta^2{}_T}$$

$$= \frac{2\left[\frac{288\,\rho_{288}}{T}\right]\left[1.64 \times 10^{-3}\left\{1260 - T\right\} h_T\right]}{\left[0.0835\,\eta_{288}\,\frac{T^{3/2}}{T + 120}\right]^2}$$

from (2), (4), (5) and (8)

$$= k_4 \, \sigma_{288} \, h_T \, F(T)$$

where

$$F(T) = \frac{(1260 - T)\;(T + 120)^2}{T^4}$$

and

$$k_4 = \frac{2 \times 288 \times 1.64 \times 10^{-3}}{421 \times 0.0835^2 \, \eta^2{}_{288}}$$

$$\therefore \frac{R}{\ell} = \left[k_4 \, \sigma_{288} \, h_T \, F(T)\right]^{\frac{1}{2}} \qquad \ldots\ldots\ldots(10)$$

In Figs.3 - 14 $\frac{U}{V}$ is plotted against $\log_e \frac{R}{\ell}$ for each fabric test specimen, the values of these being obtained from the measured quantities by means of equations (9) and (10).

These figures indicate that the results may be expressed in the form $\frac{U}{V} = m \log cR$ where m and c are constants dependent on the nature of the fabric. Because no comparative measurements of ℓ were possible numerical values of c can not be derived. The following shows how m and $\log_e c\ell$ can be obtained from the measured quantities through equations (9) and (10)

$$\frac{U}{V} = m \log_e cR$$

$$= m \log_e c\ell \left(\frac{R}{\ell}\right)$$

$$= m \log_e \left(\frac{R}{\ell}\right) + \log_e c\,\ell$$

$$\therefore m = \frac{\frac{U_2}{V_2} - \frac{U_1}{V_1}}{\log_e \left(\frac{R_2}{\ell}\right) - \log_e \left(\frac{R_1}{\ell}\right)} \qquad \text{..........(11)}$$

where the suffices 1 and 2 denote values at any two points on the curve and

$$\log_e c\ell = \frac{1}{m}\left(\frac{U}{V}\right) - \log_e \left(\frac{R}{\ell}\right) \qquad \text{..........(12)}$$

Numerical values of m and $\log_e c\,\ell$ are given in Table I for each of the fabric test specimens.

TABLE I

Details of Fabric Test Specimens

Fabric	Specification	Approx. No. of Ends	Approx. No. of Picks	Weight ozs./sq.yd.	Approx. weight in gm. of 9,000 metres of yarn	Porosity at pressure difference of 10" w.g. at 15°C and atmospheric pressure f.p.s.	m	$-\log_e c\ell$
Cotton	D.T.D.418b	99	105	1.4	52	47.3	0.043	8.1
"	"	105	106	1.4	50	38.3	0.043	9.1
"	D.T.D.524	131	140	1.6	47	25.3	0.032	9.6
"	"	131	138	1.6	45	20.5	0.029	9.8
"	D.T.D.583	55	57	2.8	195	32.6	0.030	8.1
"	D.T.D.633	63	65	3.2	196	17.3	0.022	9.6
Nylon	*	95	98	1.3	51	24.0	0.017	6.6
"	D.T.D 556A	129	117	1.6	50	14.2	0.013	8.3
"	"	126	134	1.7	50	9.4	0.013	9.9
Celanese	H1276	103	100	0.8	30	25.8	0.012	2.7
Viscose	V7721	57	51	2.9	207	22.4	0.015	6.0
Silk	D.T D.69A	108	98	1.4	55	12.8	0.015	9.4

* This fabric was produced for supplies dropping parachutes and is similar in construction to fabric to Specification D.T.D.556A except that it has fewer ends and picks. To prevent "slipping" the yarn was treated with bedafin resin in the manufacturing process.

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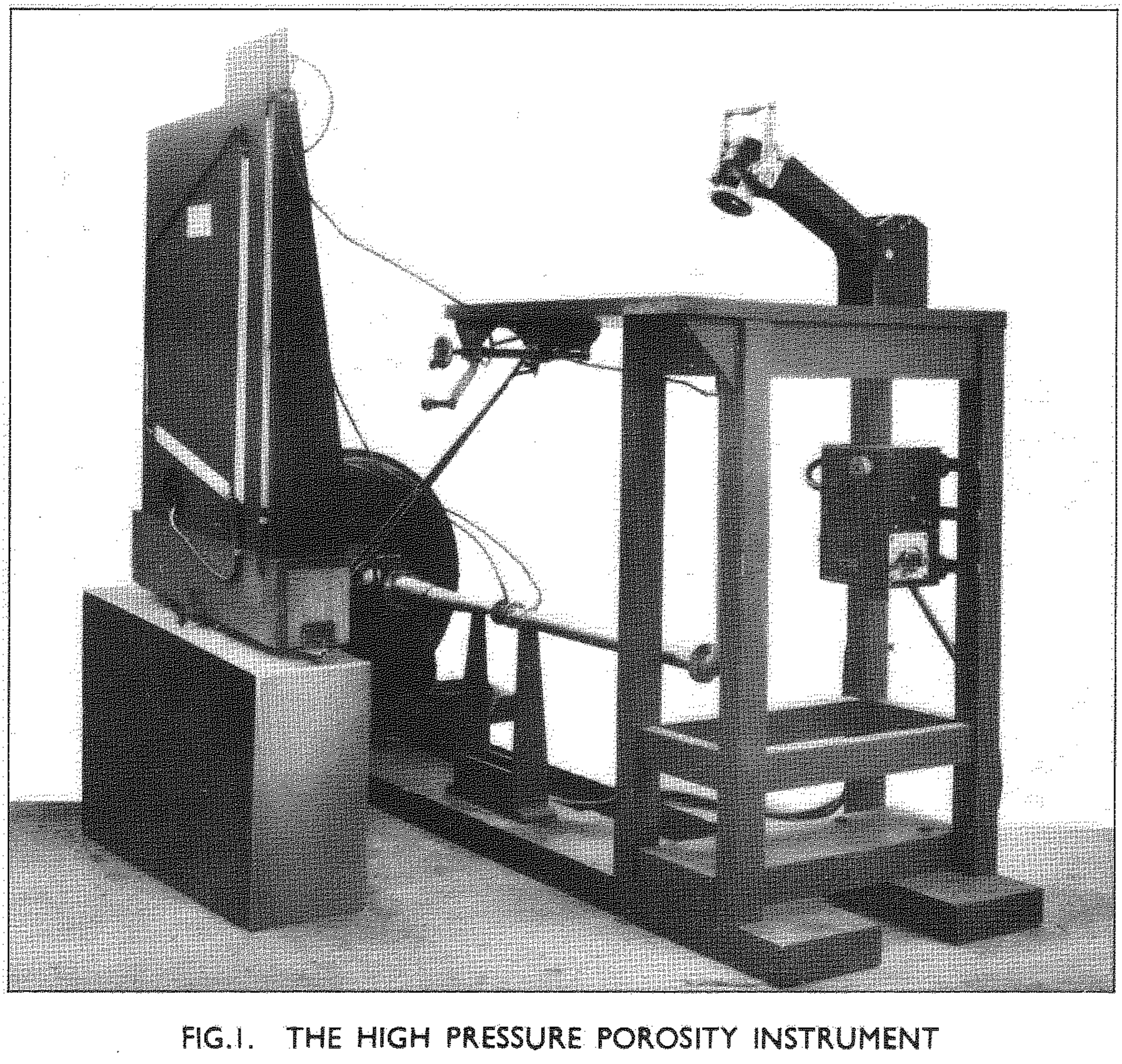

FIG. I. THE HIGH PRESSURE POROSITY INSTRUMENT

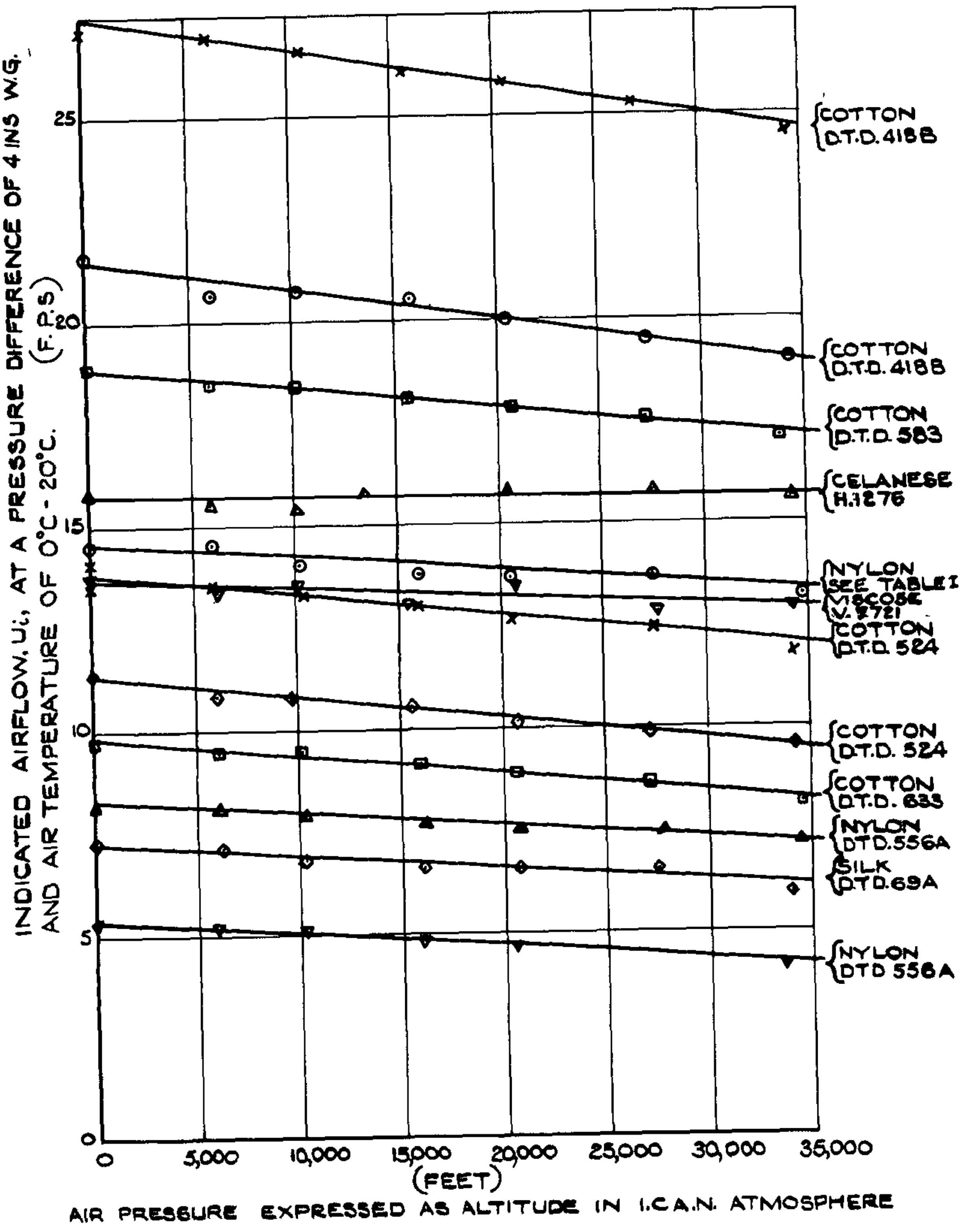

FIG. 2. VARIATION OF INDICATED AIRFLOW WITH AIR PRESSURE FOR A CONSTANT PRESSURE DIFFERENCE.

FIG. 3 & 4.

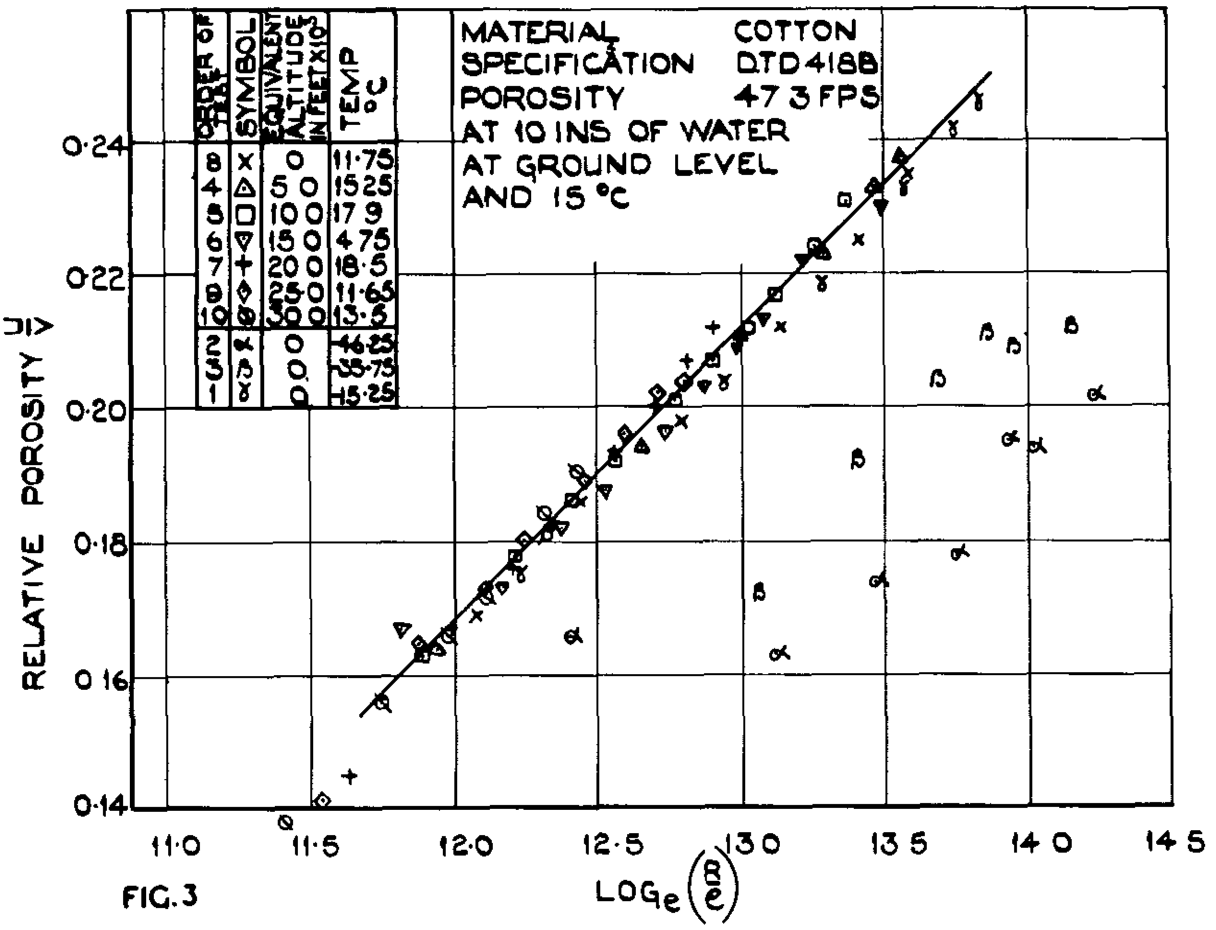

FIG. 3

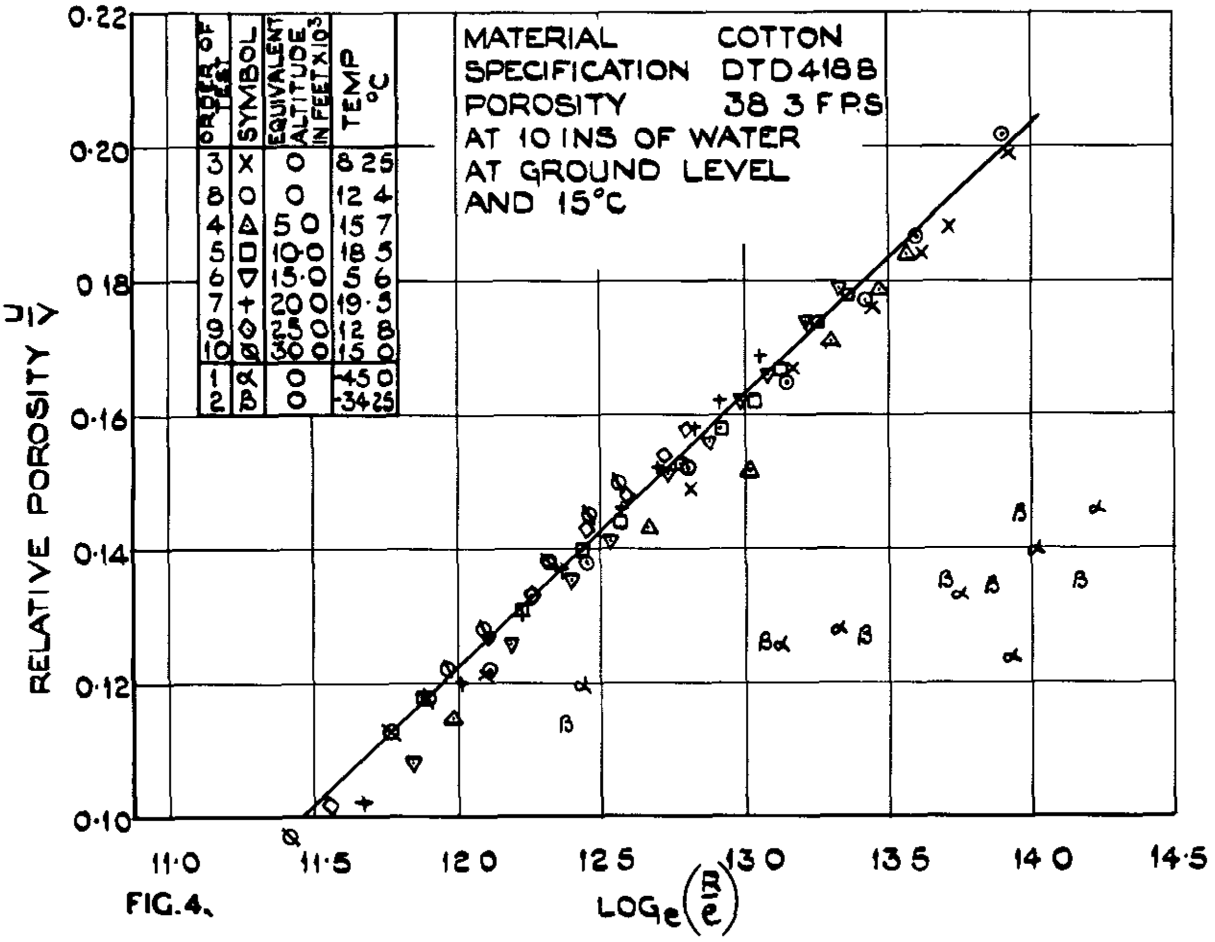

FIG. 4.

RELATIONSHIP BETWEEN RELATIVE POROSITY AND $\mathrm{LOG}_e\left(\frac{R}{\ell}\right)$

FIG. 5 & 6.

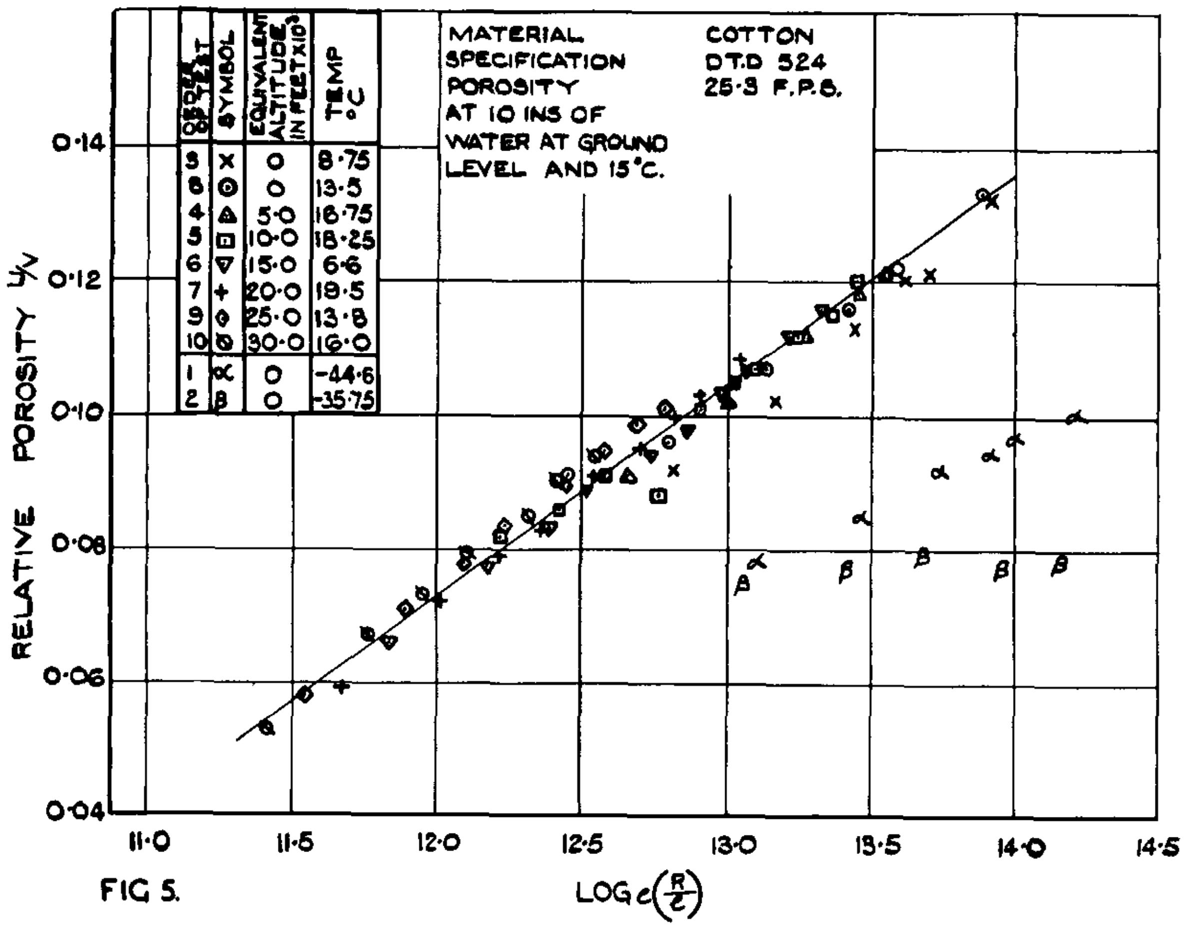

FIG 5.

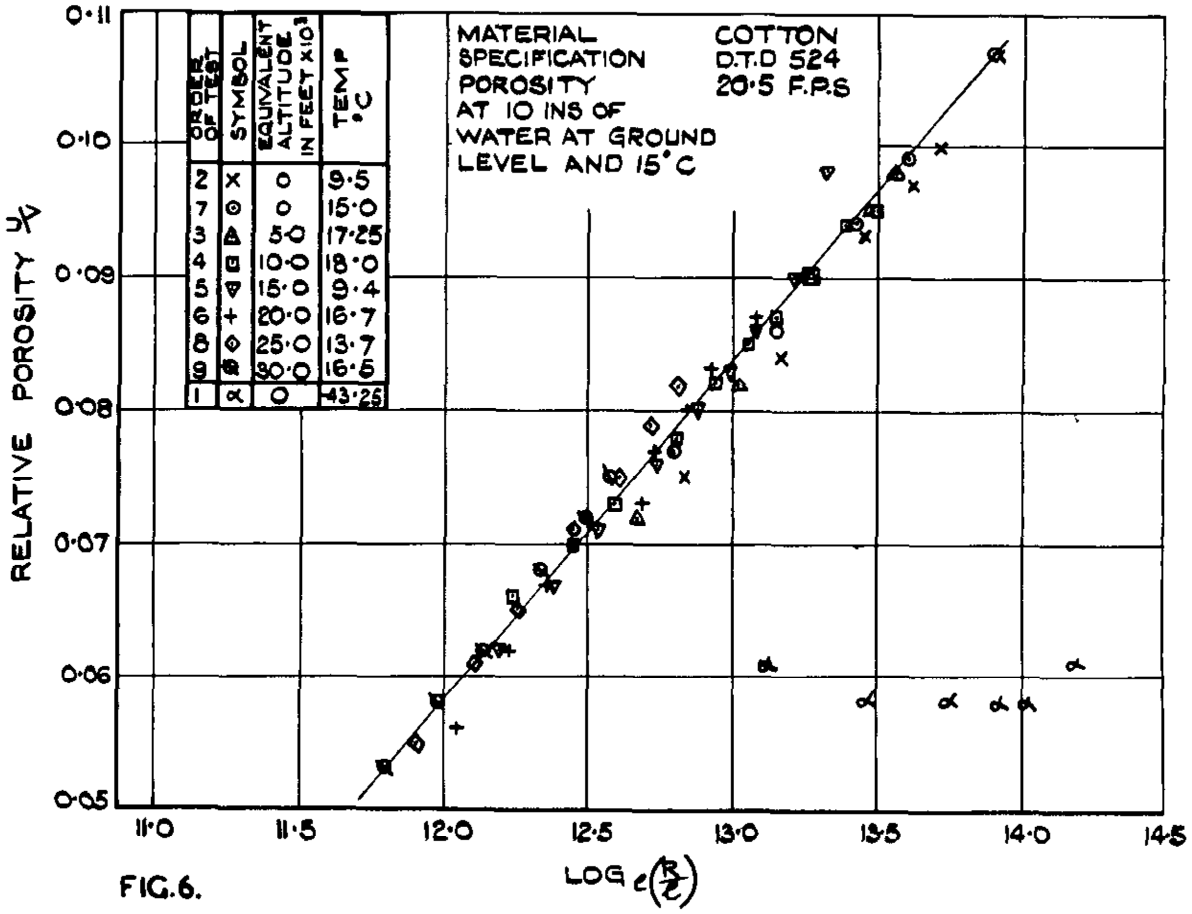

FIG.6.

RELATIONSHIP BETWEEN RELATIVE POROSITY AND LOG $_e\left(\frac{R}{\ell}\right)$

FIG. 7 & 8.

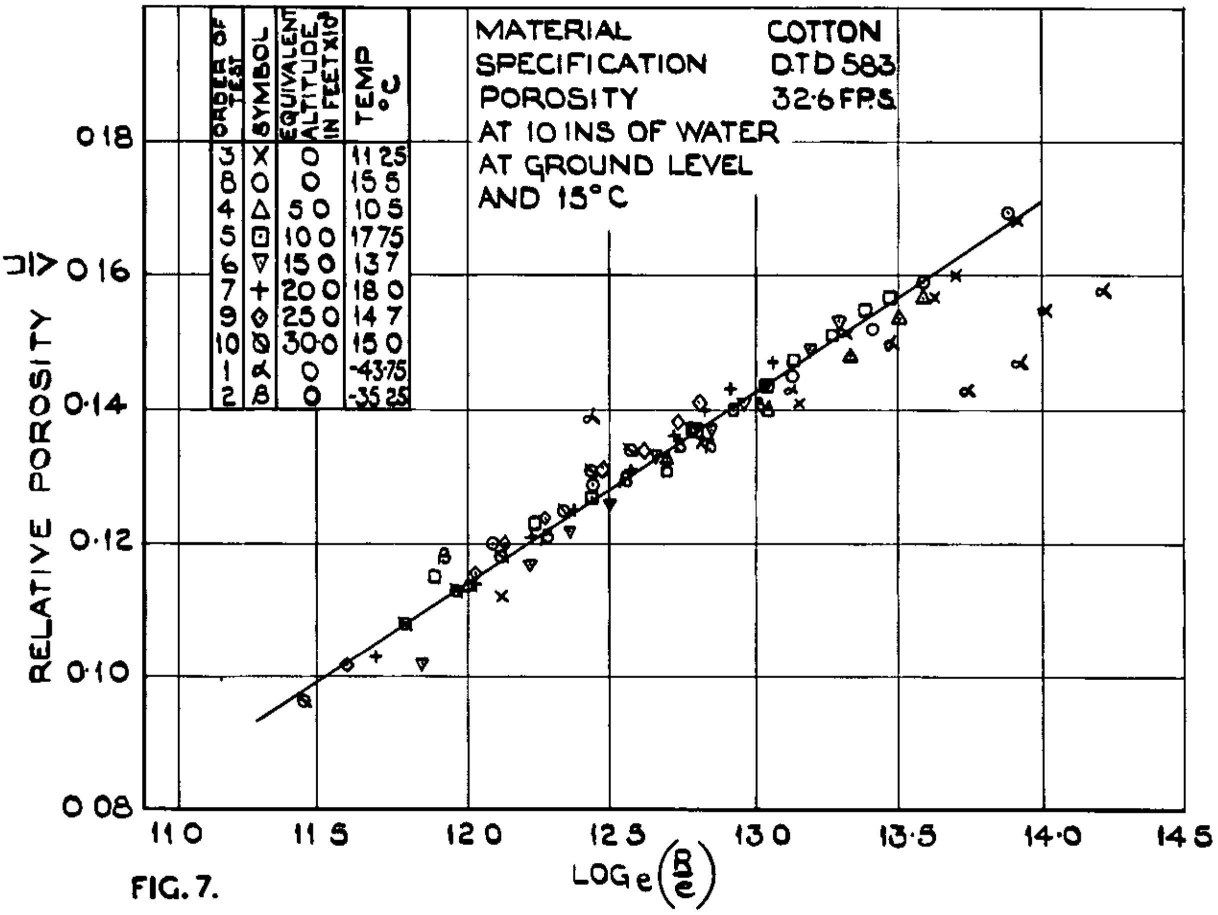

FIG. 7.

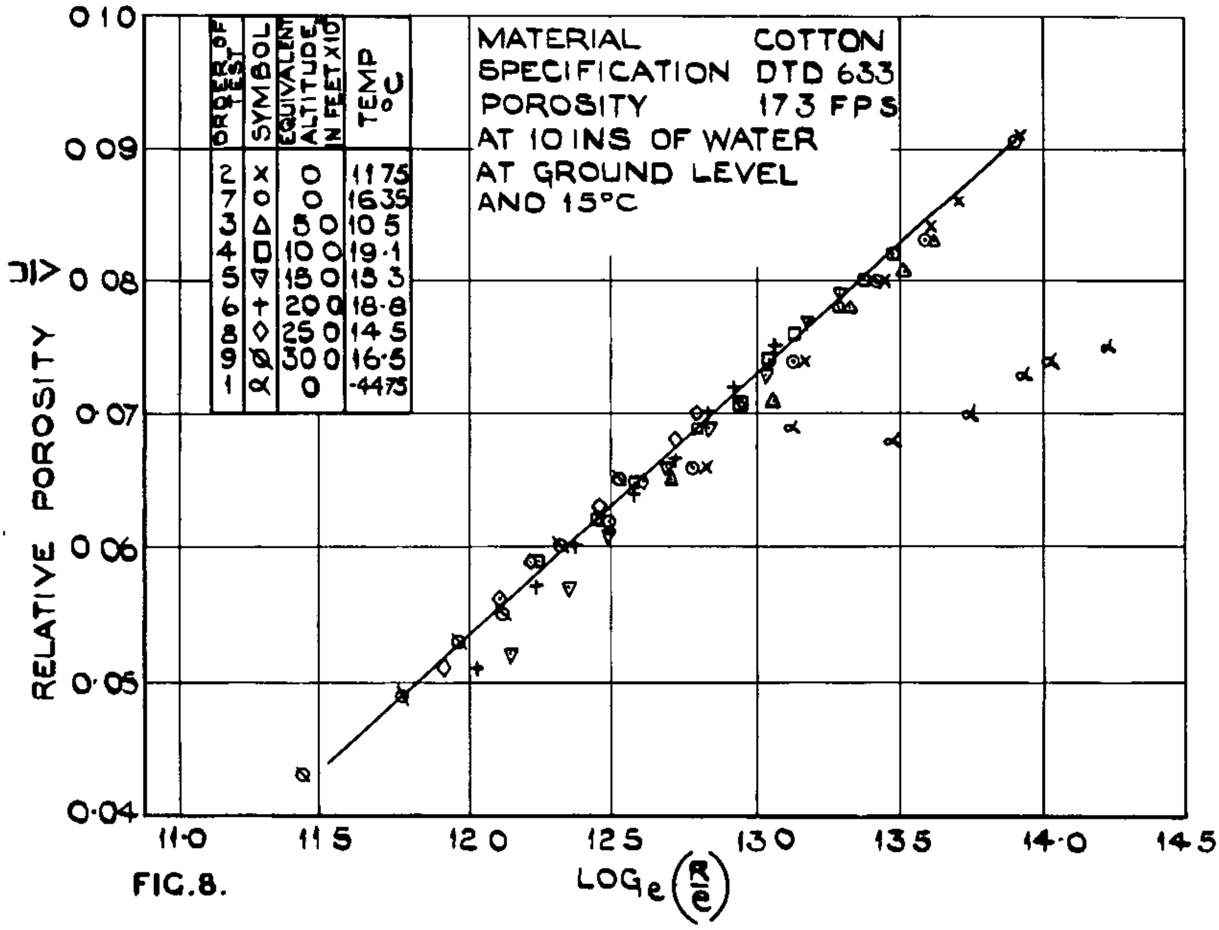

FIG. 8.

RELATIONSHIP BETWEEN RELATIVE POROSITY AND $\text{LOG}_e\left(\frac{R}{l}\right)$.

FIG. 9 & 10

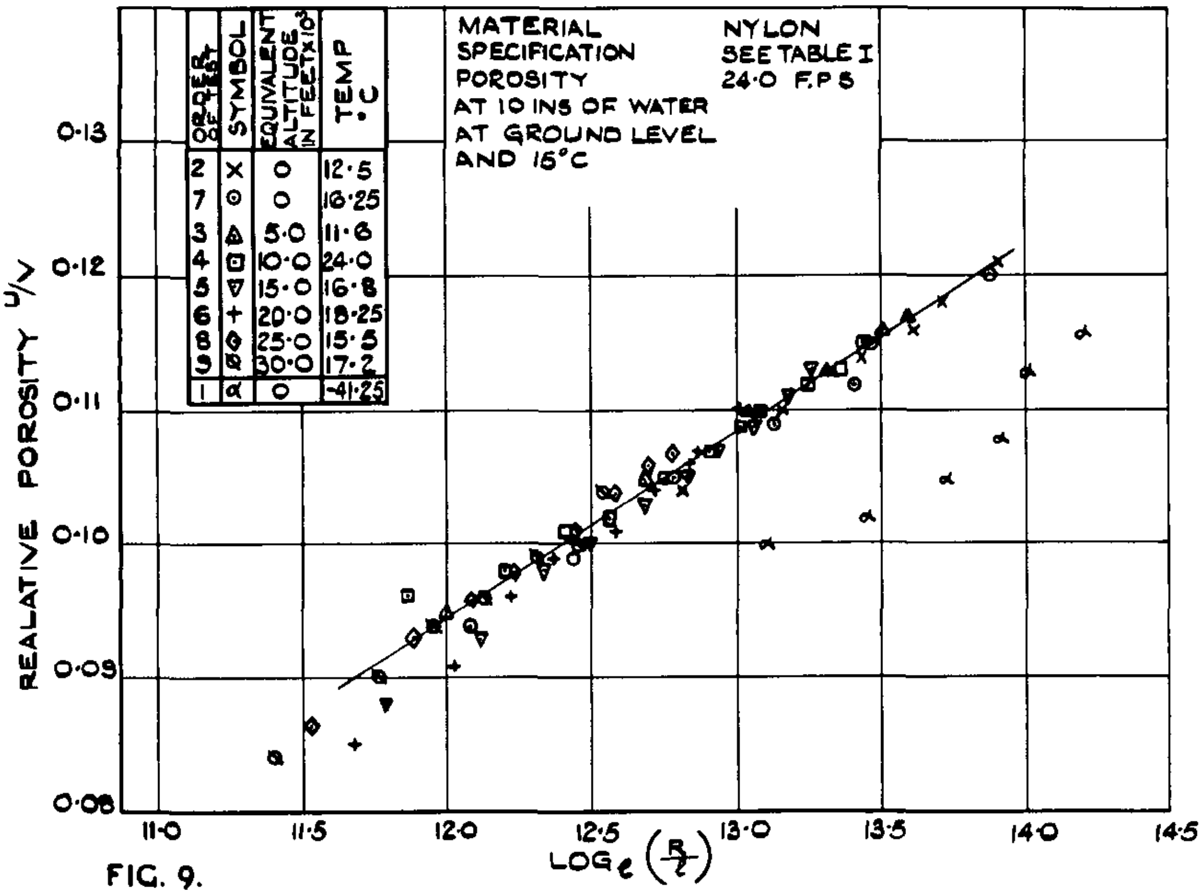

FIG. 9.

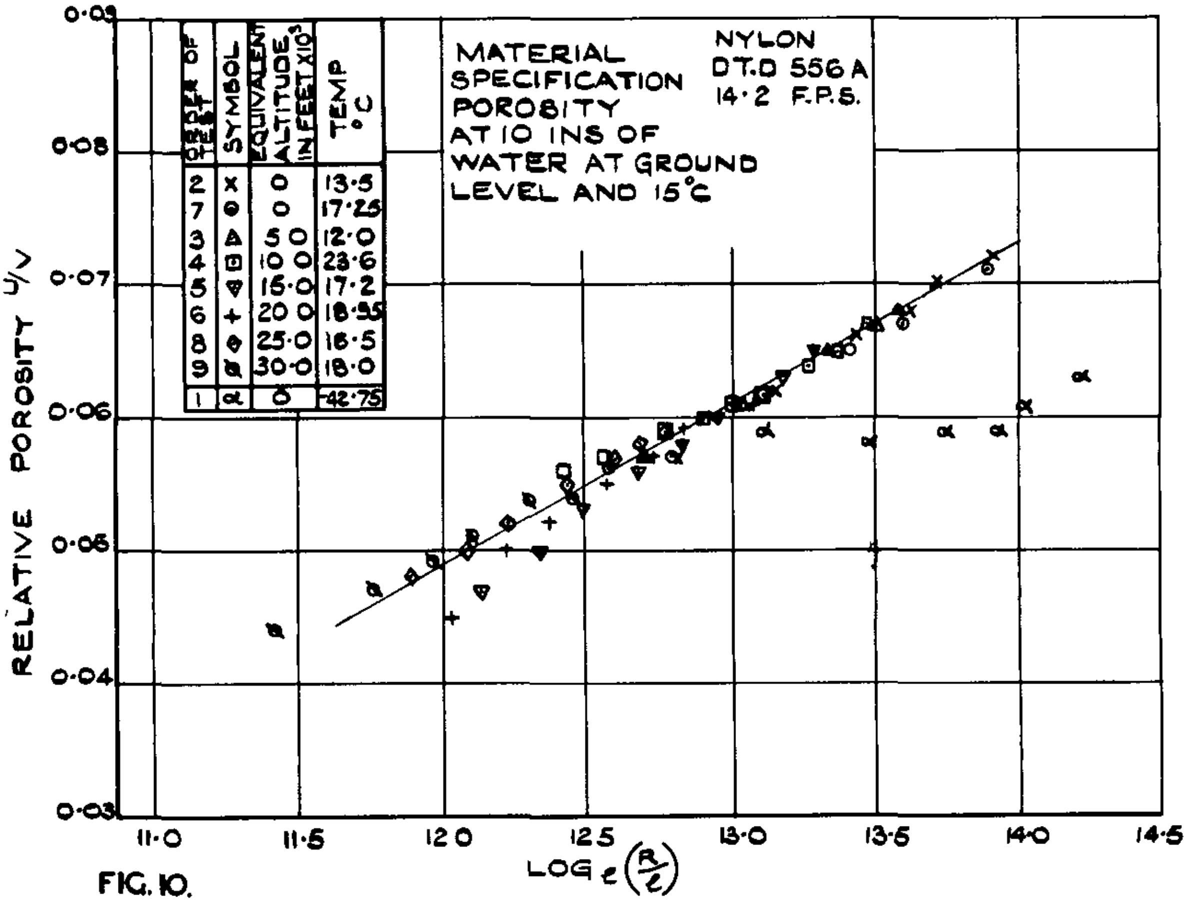

FIG. 10.

RELATIONSHIP BETWEEN RELATIVE POROSITY AND $\log_e\left(\frac{R}{\ell}\right)$

FIG. 11 & 12.

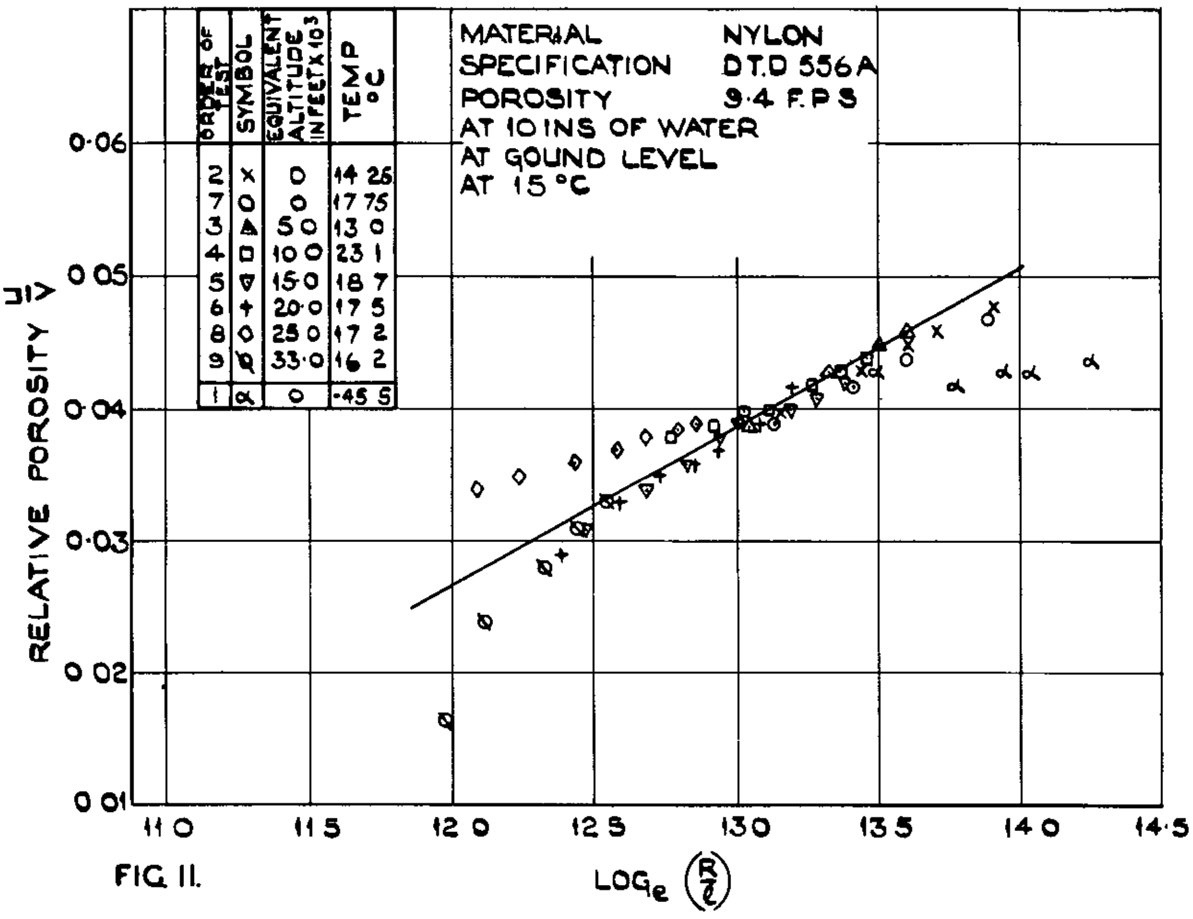

FIG. 11.

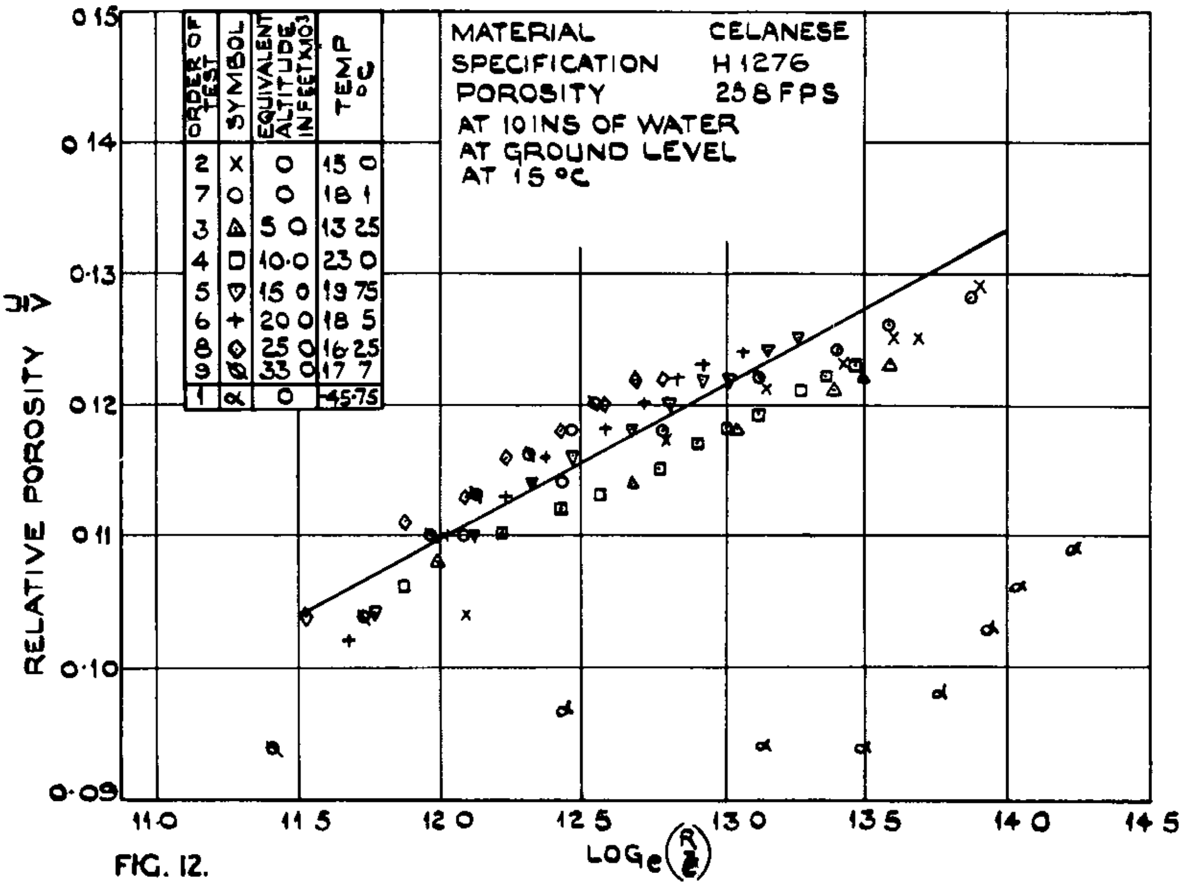

FIG. 12.

RELATIONSHIP BETWEEN RELATIVE POROSITY AND $\text{LOG}_e\left(\frac{R}{\ell}\right)$

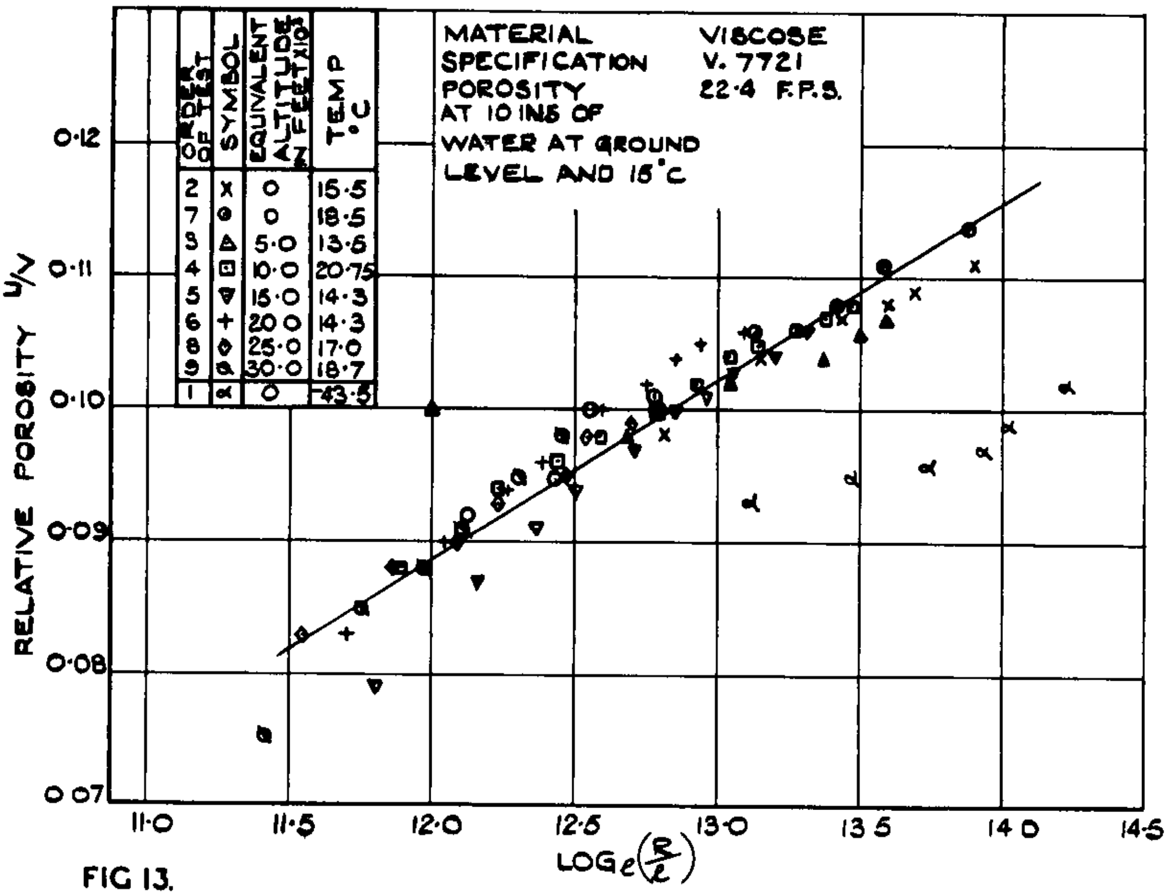

FIG 13.

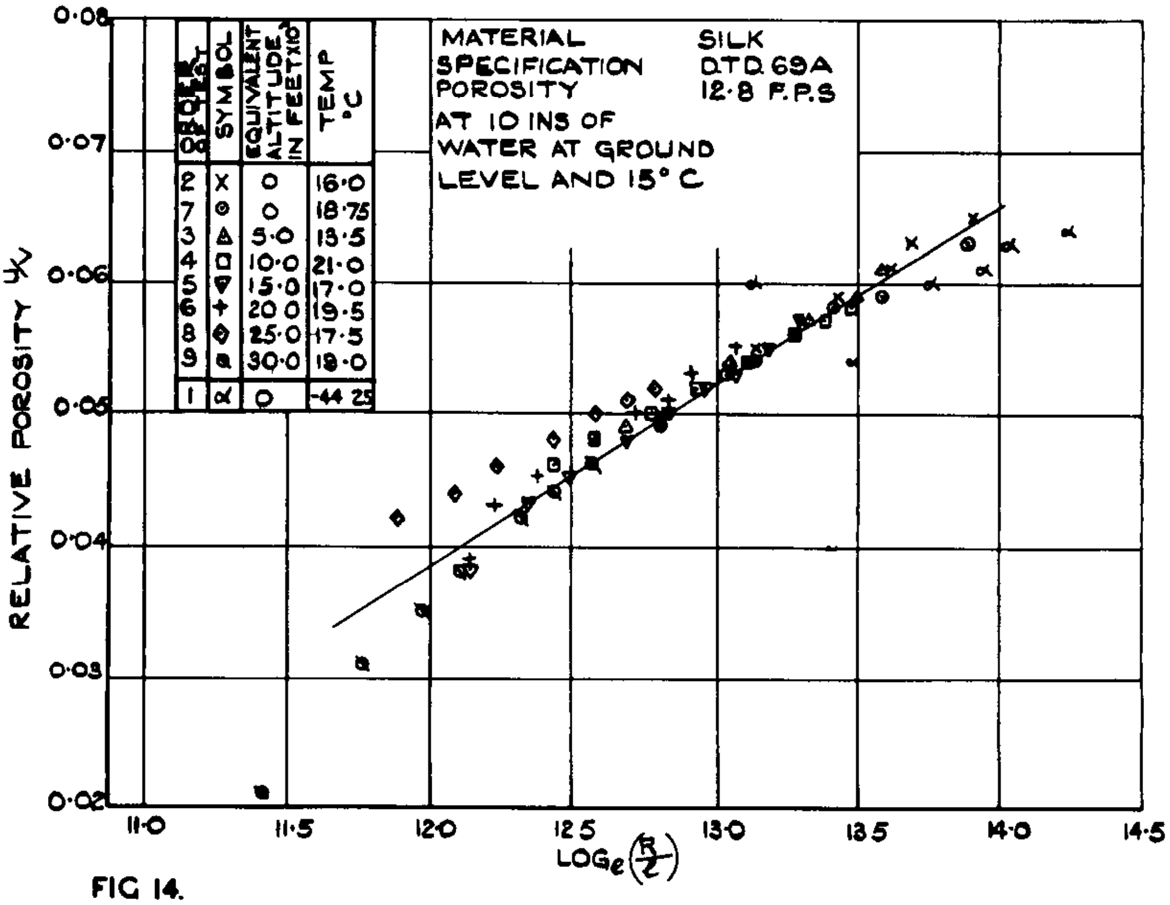

FIG 14.

RELATIONSHIP BETWEEN RELATIVE POROSITY AND LOG$_e$(R/ℓ)

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