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Permeability of Two Parachute Fabrics – Measurements, Modeling, and Application

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July 2016

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Summary

Two parachute fabrics, described by Parachute Industry Specifications PIA-C-7020D Type I and PIA-C-44378D Type I, were tested to obtain their permeabilities in air (i.e., flow-through volume of air per area per time) over the range of differential pressures from 0.146 psf (7 Pa) to 25 psf (1197 Pa). Both fabrics met their specification permeabilities at the standard differential pressure of 0.5 inch of water (2.60 psf, 124 Pa). The permeability results were transformed into an effective porosity for use in calculations related to parachutes. Models were created that related the effective porosity to the unit Reynolds number for each of the fabrics. As an application example, these models were used to calculate the total porosities for two geometrically-equivalent subscale Disk-Gap-Band (DGB) parachutes fabricated from each of the two fabrics, and tested at the same operating conditions in a wind tunnel. Using the calculated total porosities and the results of the wind tunnel tests, the drag coefficient of a geometrically-equivalent full-scale DGB operating on Mars was estimated.

Symbols and Abbreviations

C_D	parachute drag coefficient (using S_0 as the reference area)
C_0, C_1	constants in the linear relationships between λ_T and C_D ; the additional subscripts $M1$ and $M2$ are added to these symbols to denote which method was used to determine λ_T
c_e	effective porosity
$c_{e,\text{Avg}}$	average effective porosity
K_1, K_2	constants in the models for c_e
k	discharge coefficient
p	atmospheric (upstream) pressure (in the laboratory)
q	dynamic pressure
R	gas constant
$\hat{Re}$	unit Reynolds number
$\hat{Re}_{\text{Avg}}$	average unit Reynolds number
RH	relative humidity (in the laboratory)
S	constant in Sutherland's formula for μ
S_p	parachute inflated projected area
S_0	parachute nominal area (used as the reference area for C_D)
T	temperature (in the laboratory)
U	fictitious freestream airspeed
u	permeability
u_{Avg}	average permeability
u_{Max}	maximum permeability
u_{Min}	minimum permeability
u_R	permeability range, $u_{\text{Max}} - u_{\text{Min}}$
β	constant in Sutherland's formula for μ
Δp	differential pressure
λ_g	parachute geometric porosity
λ_T	parachute total porosity; the additional subscripts $M1$ and $M2$ are added to λ_T when necessary to denote which method was used in its calculation
μ	coefficient of viscosity
ρ	fluid density
DGB	Disk-Gap-Band (parachute type)
MSL	Mars Science Laboratory
PIA	Parachute Industry Association
PST	Pacific Standard Time
TDT	Transonic Dynamics Tunnel

1 Introduction

Recently, a wind tunnel test of subscale model parachutes was conducted at the NASA Langley Research Center Transonic Dynamics Tunnel (TDT) (ref. 1). To quantify the effect of fabric permeability[1] on the parachute's aerodynamic characteristics, subscale model parachutes of nominally identical geometries were fabricated from each of two fabrics. These two fabrics had very different permeability characteristics (i.e., permeability values at given differential pressures). The permeabilities of both fabrics were needed over a wide range of differential pressures to fully exploit the results of the wind tunnel test.

This technical memorandum describes tests conducted to obtain the needed fabric permeability data. Using these data, the effective porosities of the fabrics are calculated and mathematically modeled. These mathematical models are then applied to the determination of the parachute's total porosity and evaluation of the effect of fabric permeability on the parachute's drag coefficient.

2 Permeability Testing

2.1 Fabrics

The two parachute fabrics used in the permeability testing were PIA-C-7020D Type I and PIA-C-44378D Type I as described by Parachute Industry Association (PIA) specifications (refs. 2 and 3, respectively). Both fabrics were woven from nylon fibers. Key specification properties of these two fabrics are given in table 1.

Table 1. Key specification properties of the test fabrics.

Fabric	Weave	Areal Weight (Max)	Permeability
PIA-C-7020D Type I	Rip Stop	1.10 oz/yd^2 37.3 g/m^2	100 ± 20 ft^3/ft^2/min 50.8 ± 10.2 cm^3/cm^2/s
PIA-C-44378D Type I	Rip Stop	1.20 oz/yd^2 40.7 g/m^2	0.5 - 5.0 ft^3/ft^2/min 0.25 - 2.5 cm^3/cm^2/s

Specification properties from references 2 (PIA-C-7020D Type I fabric) and 3 (PIA-C-44378D Type I fabric). Permeability values when tested per ASTM International Test Method D737 (ref. 4) at a differential pressure of 0.5 inch of water (2.60 psf, 124 Pa).

2.2 Test Instrument

Testing was conducted in air using a Textest Instruments FX 3300 Labotester III Air Permeability Tester (see figure 1). This instrument was located at the Quality Assurance Laboratory of the Escape, Parachute and Crashworthy Division at the Naval Air Warfare Center Weapons Division in China Lake, California. At the time testing was conducted, this instrument had a valid calibration. The sample test region was circular with a diameter of 2.75 in (6.99 cm)

[1] Fabric permeability is the flow-through volume of air per area per time.

and an area of 5.94 in^2 (38.3 cm^2). Operation of this instrument involved selecting the differential pressure (in integer increments of Pa) and measuring the resultant permeability. The instrument manufacturer stated that the differential pressure and permeability measurements have an expected uncertainty of ±5 percent for differential pressures less than 2.05 psf (98 Pa), and ±3 percent at higher differential pressures.

Figure 1. Test instrument. Portion of fabric being tested is inside circular clamp.

2.3 Test Samples

The two fabrics used in the permeability testing were from the same lots as those used to fabricate the model parachutes used during the wind tunnel test described in reference 1.

For each fabric, a single piece of approximately 1 yd^2 (0.8 m^2) in area was provided to the testing laboratory. Five samples were selected from each of these pieces of fabric. The locations of the samples, and the numbering scheme used to identify them, are shown in figure 2. Each square in this figure was approximately 6.5 × 6.5 in (16.5 × 16.5 cm). Placing samples near the fabric edges was avoided. The samples were not cut from the fabric provided; the test instrument allowed for testing without cutting the fabric. Figure 1 shows a sample in place for testing.

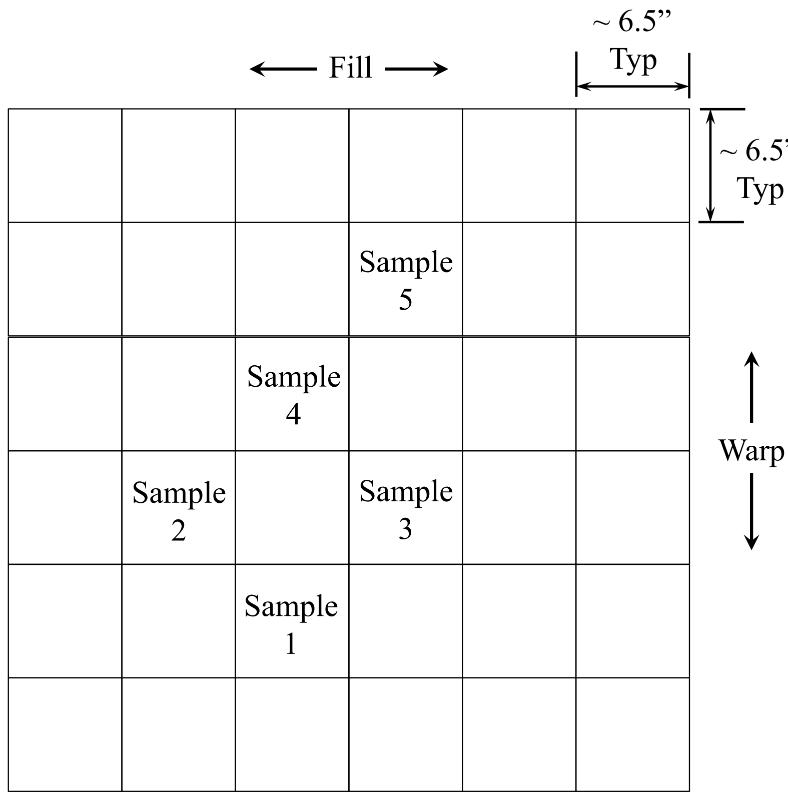


Figure 2. Position of samples on fabrics.

2.4 Test Matrix

The test matrix is given in table 2. Each sample was tested at ten values of differential pressure from 0.146 psf (7 Pa) to 25 psf (1197 Pa). The differential pressure range was selected to satisfy the analysis needs of the parachute data in reference 1. Testing for each sample was conducted in the order shown in table 2, always starting and concluding with the lowest differential pressure (0.146 psf, 7 Pa). Repeating the first differential pressure at the end of the test for each sample provided data for partial evaluation of the repeatability of the results. The test sequence for Samples 1 and 5 were the same; this was done to evaluate sample-to-sample (i.e., location) variation in the results. Note that, except for the last test in the test sequence, the differential pressures used for Samples 1 and 5 increased monotonically. For Samples 2–4, the test sequence of differential pressure values between the first and last test were randomized in an attempt to evaluate the effect of test sequence. Following the completion of the tests listed in table 2, replicate tests of Sample 3 (both fabric types) and Sample 4 (PIA-C-44378D Type I only) were conducted to evaluate the effect of test-to-test variation.

Table 2. Test matrix.

Customary Units

Sample	Differential Pressure, Δp (psf)										
1	0.146	0.251	0.501	0.752	1.003	2.047	3.008	5.994	12.009	25.000	0.146
2	0.146	1.003	3.008	0.251	0.501	5.994	25.000	12.009	0.752	2.047	0.146
3	0.146	0.251	2.047	12.009	5.994	0.752	25.000	1.003	0.501	3.008	0.146
4	0.146	3.008	1.003	25.000	2.047	0.251	5.994	0.752	0.501	12.009	0.146
5	0.146	0.251	0.501	0.752	1.003	2.047	3.008	5.994	12.009	25.000	0.146

SI Units

Sample	Differential Pressure, Δp (Pa)										
1	7.00	12.00	24.00	36.00	48.00	98.00	144.00	287.00	575.00	1197.00	7.00
2	7.00	48.00	144.00	12.00	24.00	287.00	1197.00	575.00	36.00	98.00	7.00
3	7.00	12.00	98.00	575.00	287.00	36.00	1197.00	48.00	24.00	144.00	7.00
4	7.00	144.00	48.00	1197.00	98.00	12.00	287.00	36.00	24.00	575.00	7.00
5	7.00	12.00	24.00	36.00	48.00	98.00	144.00	287.00	575.00	1197.00	7.00

2.5 Test Procedure

Twenty-four hours prior to testing, the fabric pieces were unfolded and set aside so that they could reach equilibrium with the laboratory's environmental condition (which were almost constant). Testing was conducted at the laboratory's temperature and relative humidity. Each sample was installed on the test instrument as shown in figure 1. Testing proceeded in the sequence shown in table 2 by setting the desired differential pressure and recording the measured permeability. A given sample was tested in the specified differential pressure sequence without being reset (i.e., removed and reinstalled) in the test instrument. After each test (i.e., permeability measurement at a specific differential pressure) the differential pressure was reduced to zero and the sample was allowed to "rest" for approximately four minutes before testing at the next value of the differential pressure.

2.6 Data Acquisition

The following quantities were recorded during testing:

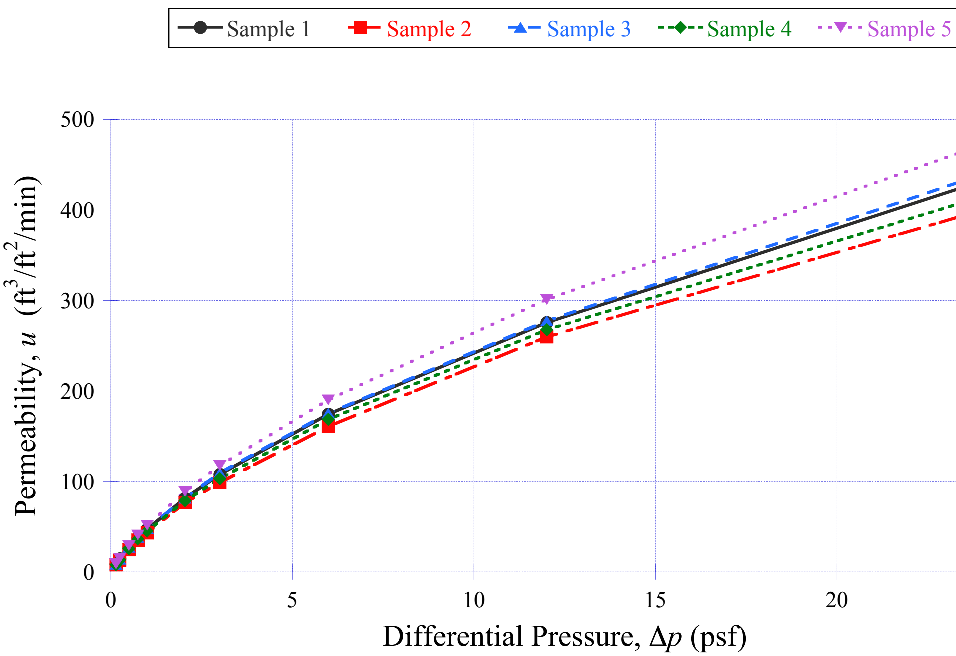
- Fabric
- Sample number
- Date and time of test
- Atmospheric (upstream) pressure (in the laboratory), p (in. Hg)
- Atmospheric temperature (in the laboratory), T (°F)
- Relative humidity (in the laboratory), RH (%)
- Differential pressure, Δp (Pa)
- Permeability, u (ft^3/ft^2/min or cm^3/cm^2/s)

3 Permeability Test Results

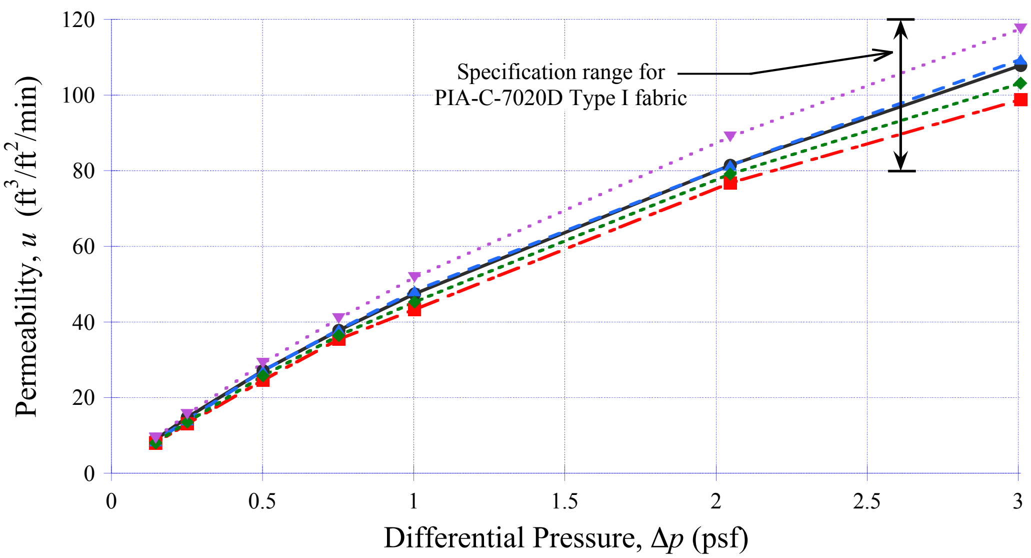
The permeability results are shown graphically in figures 3 and 4, and in summary in tables 3 and 4 (for PIA-C-7020D Type I and PIA-C-44378D Type I fabrics, respectively). A complete set of permeability results is presented in tables in Appendix A.

Several observations can be made from these results:

1. The permeability of both fabrics increases with differential pressure over the range of differential pressures used in the test.
2. The permeability of the PIA-C-7020D Type I fabric is much greater (> 25X) than that of the PIA-C-44378D Type I fabric.
3. Both fabrics met their permeability specifications (see figures 3b and 4b).
4. The variation in the permeability results at a given differential pressure was significant. For the PIA-C-7020D Type I fabric the permeability range divided by the average value was in the range from 0.15 to 0.18 over the tested differential pressure range (see table 3). For the PIA-C-44378D Type I fabric the permeability range divided by the average value was in the range from 0.25 to 0.30 over the tested differential pressure range (see table 4).
5. For a given fabric, the principal source of variation in the results seemed to be the sample location within the piece of fabric provided for testing. This observation was supported by the difference in the results between Samples 1 and 5, which were tested using the same test sequence (see table 2). The test sequence did not seem to be a significant source of the observed variation. Additional replicate testing (see Appendix B) indicated that test-to-test variation was not the principal source of the variation.

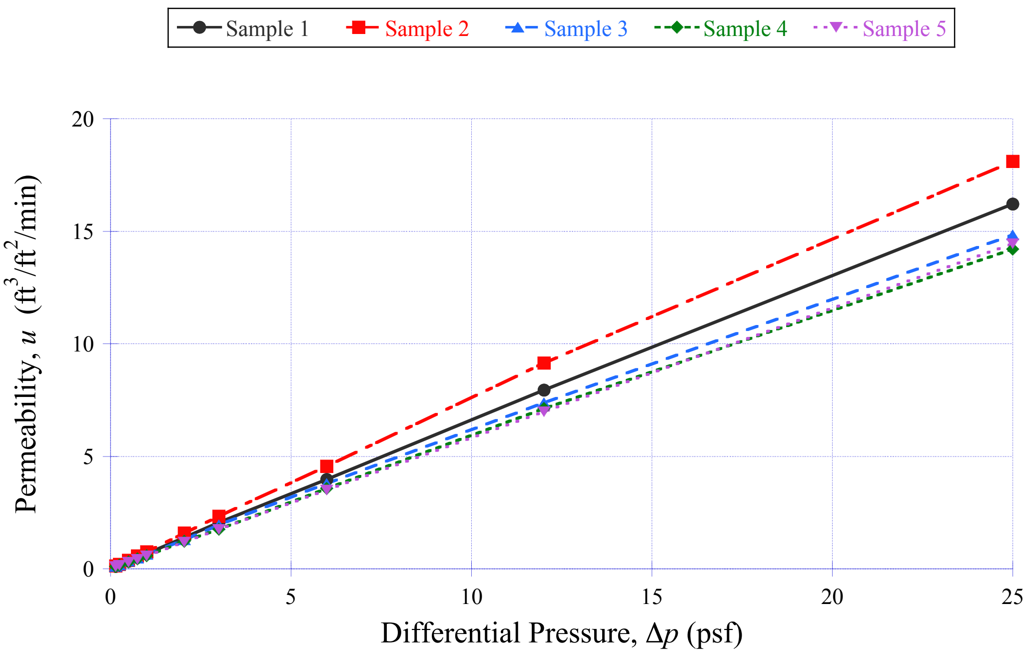


(a) Full differential pressure range: 0.146-25 psf (7-1197 Pa).

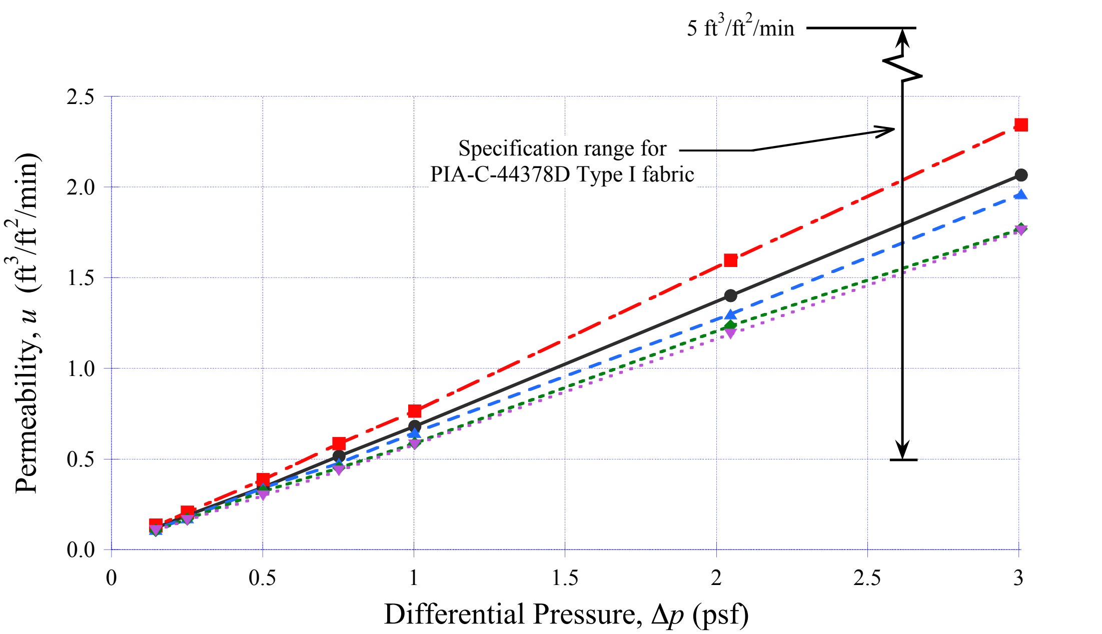


(b) Close up of the lower differential pressure range: 0.146–3 psf (7–143.6 Pa).

Figure 3. Permeability results for PIA-C-7020D Type I fabric.



(a) Full differential pressure range: 0.146–25 psf (7–1197 Pa).



(b) Close up of the lower differential pressure range: 0.146–3 psf (7–143.6 Pa).

Figure 4. Permeability results for PIA-C-44378D Type I fabric.

Table 3. Summary of permeability results for PIA-C-7020D Type I fabric.

Diff. Pres. Δp	Avg. Permeability u_{Avg}	Min Permeability u_{Min}	Max Permeability u_{Max}	Permeability Range $u_R = u_{\text{Max}} - u_{\text{Min}}$	Diff. Pres. Δp	Avg. Permeability u_{Avg}	Min Permeability u_{Min}	Max Permeability u_{Max}	Permeability Range $u_R = u_{\text{Max}} - u_{\text{Min}}$	Range/Avg. Permeability u_R/u_{Avg}
(psf)	($ft^3/ft^2/min$)				(Pa)	($cm^3/cm^2/s$)				-
0.146	8.57	7.95	9.41	1.46	7.0	4.36	4.04	4.78	0.74	0.17
0.251	14.21	13.13	15.55	2.42	12.0	7.22	6.67	7.90	1.23	0.17
0.501	26.77	24.61	29.13	4.53	24.0	13.60	12.50	14.80	2.30	0.17
0.752	37.72	35.43	40.94	5.51	36.0	19.16	18.00	20.80	2.80	0.15
1.003	47.20	43.31	51.77	8.46	48.0	23.98	22.00	26.30	4.30	0.18
2.047	81.57	76.77	88.98	12.20	98.0	41.44	39.00	45.20	6.20	0.15
3.008	107.36	98.82	117.52	18.70	144.0	54.54	50.20	59.70	9.50	0.17
5.994	173.90	160.83	190.16	29.33	287.0	88.34	81.70	96.60	14.90	0.17
12.009	276.38	259.84	301.18	41.34	575.0	140.40	132.00	153.00	21.00	0.15
25.000	444.49	411.42	486.22	74.80	1197.0	225.80	209.00	247.00	38.00	0.17

Table 4. Summary of permeability results for PIA-C-44378D Type I fabric.

Diff. Pres. Δp	Avg. Permeability u_{Avg}	Min Permeability u_{Min}	Max Permeability u_{Max}	Permeability Range $u_R = u_{\text{Max}} - u_{\text{Min}}$	Diff. Pres. Δp	Avg. Permeability u_{Avg}	Min Permeability u_{Min}	Max Permeability u_{Max}	Permeability Range $u_R = u_{\text{Max}} - u_{\text{Min}}$	Range/Avg. Permeability u_R/u_{Avg}
(psf)	($ft^3/ft^2/min$)				(Pa)	($cm^3/cm^2/s$)				-
0.146	0.115	0.103	0.135	0.032	7.0	0.0586	0.0525	0.0686	0.0161	0.27
0.251	0.180	0.162	0.207	0.045	12.0	0.0916	0.0822	0.1050	0.0228	0.25
0.501	0.338	0.297	0.386	0.089	24.0	0.1716	0.1510	0.1960	0.0450	0.26
0.752	0.493	0.435	0.585	0.150	36.0	0.2502	0.2210	0.2970	0.0760	0.30
1.003	0.651	0.579	0.764	0.185	48.0	0.3308	0.2940	0.3880	0.0940	0.28
2.047	1.344	1.189	1.596	0.407	98.0	0.6828	0.6040	0.8110	0.2070	0.30
3.008	1.980	1.758	2.343	0.585	144.0	1.0058	0.8930	1.1900	0.2970	0.30
5.994	3.886	3.504	4.567	1.063	287.0	1.9740	1.7800	2.3200	0.5400	0.27
12.009	7.720	6.988	9.154	2.165	575.0	3.9220	3.5500	4.6500	1.1000	0.28
25.000	15.567	14.213	18.110	3.898	1197.0	7.9080	7.2200	9.2000	1.9800	0.25

Note: In tables 3 and 4 above, data for all samples at a specific differential pressure (original tests only, not including replicates) were used to determine the average, minimum, maximum, and range of permeabilities.

4 Effective Porosity Test Results, Modeling, and Application

To make full use of the results presented in the previous section, the fabric permeability needs to be transformed to a quantity that allows for the determination of its contribution to the parachute's porosity. This transformation is accomplished by calculating an effective porosity from the fabric permeability results. The approach followed herein to obtain, model, and apply effective porosity closely follows that presented by Lingard and Underwood in reference 5 and in unpublished lecture notes by Lingard in reference 6.

4.1 Effective Porosity Test Results

An effective porosity, c_e, can be defined as

$$c_e = \frac{u}{U} \tag{1}$$

where u is the fabric permeability (interpreted here as an airspeed through the fabric), and U is a fictitious freestream airspeed[2] related to freestream dynamic pressure. The value of U is determined from the differential pressure across the fabric,

$$\Delta p = \tfrac{1}{2}\rho U^2 \tag{2}$$

where ρ is the density of the fluid. In the present analyses, the fluid is considered to be incompressible. From theoretical considerations, c_e can be modeled as a function of the unit Reynolds number $\hat{R}e$ using U as the reference airspeed:

$$\hat{R}e = \frac{\rho U}{\mu} \tag{3}$$

where μ is the coefficient of viscosity (dynamic viscosity) of the fluid.

From the permeability results already presented, c_e and $\hat{R}e$ were calculated for both fabrics from equations (1)–(3) using the following additional equations and constants: the equation of state and the gas constant for air, R, (ref. 8)

$$\rho = \frac{p}{RT} \tag{4a}$$

[2] See reference 7, Section III – The Concept of Effective Porosity, pp. 10–12.

$$R = 1716.57\ \frac{\text{ft•lb}}{\text{slug•°R}} \quad \left(287.053\ \frac{\text{N•m}}{\text{kg•K}}\right) \tag{4b}$$

and Sutherland's formula for μ, and its constants β and S for air (ref. 8)

$$\mu = \frac{\beta T^{\frac{3}{2}}}{S + T} \tag{5a}$$

$$\beta = 1.458 \bullet 10^{-6}\ \frac{\text{kg}}{\text{m•s•K}^{\frac{1}{2}}} \tag{5b}$$

$$S = 110.4\ \text{K} \tag{5c}$$

The value of μ was calculated in SI units (N•s/m^2) using the equation and constants from reference 8 and then converted to U.S. Customary Units (lb•s/ft^2).

The original permeability results (i.e., those presented in Appendix A) were processed to yield c_e vs. $\hat{Re}$. These effective porosity results are shown by symbols in figures 5 and 6, and in summary (averaging points at the same value of Δp) in table 5 for both PIA-C-7020D Type I and PIA-C-44378D Type I fabrics. A complete set of effective porosity results are given in tables in Appendix C.

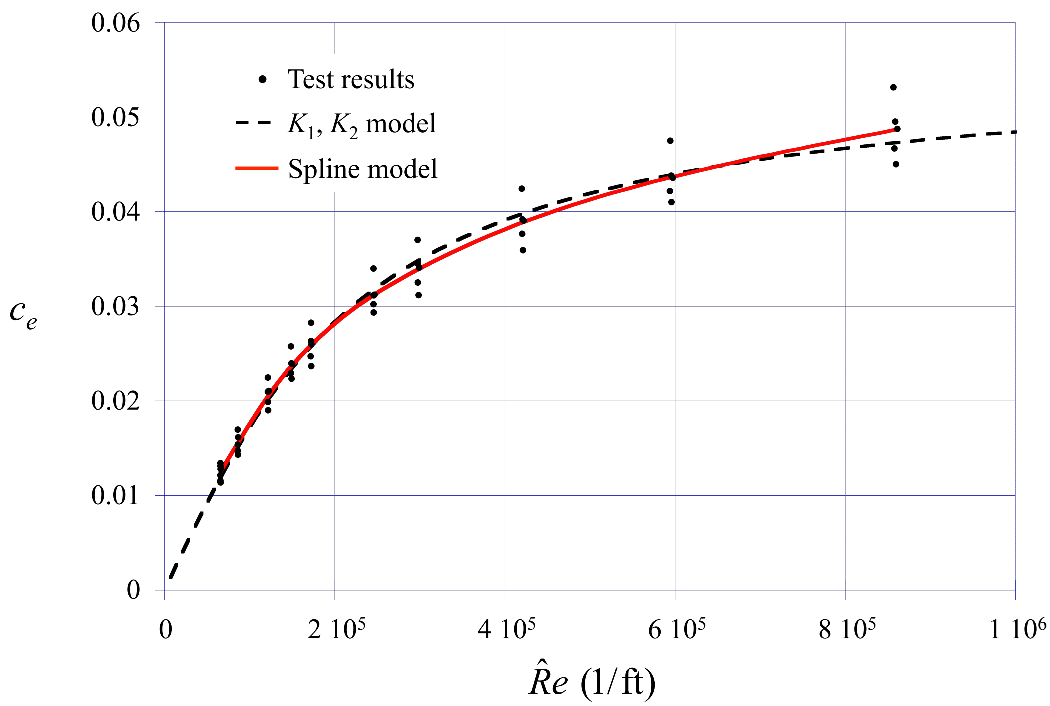


Figure 5. Effective porosity results and models for PIA-C-7020D Type I fabric.

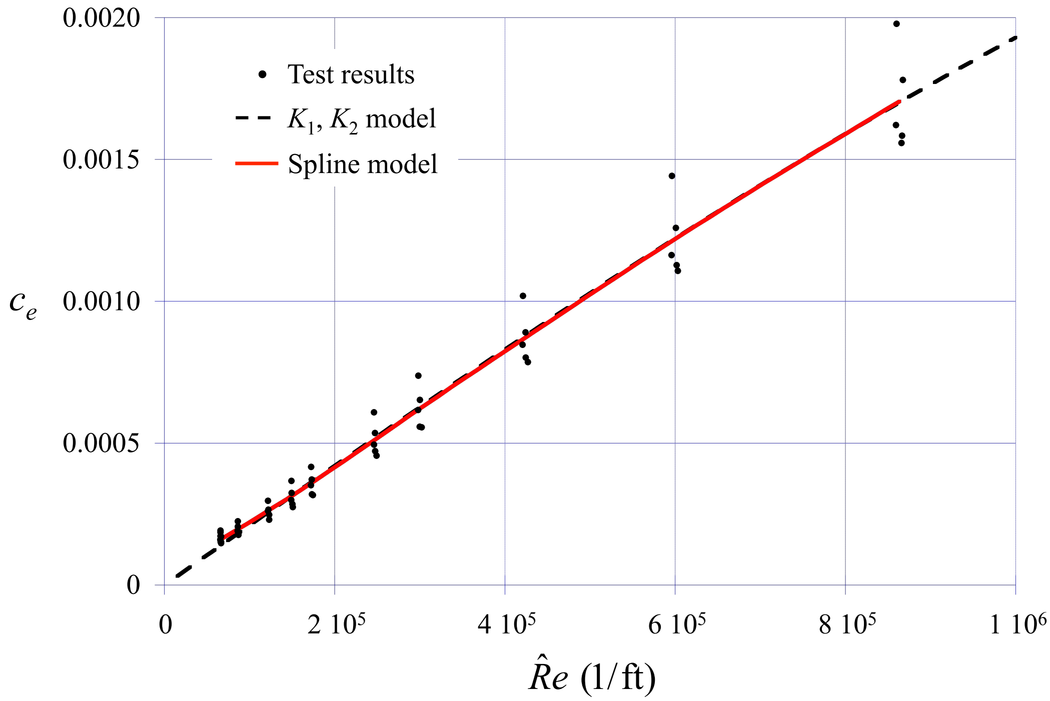


Figure 6. Effective porosity results and models for PIA-C-44378D Type I fabric.

Table 5. Effective porosity results and spline model.

PIA-C-7020D Type I Fabric				PIA-C-44378D Type I Fabric			
$\hat{R}e_{\text{Avg}}$		$c_{e,\text{Avg}}$ Avg. Test Results	c_e Spline Model	$\hat{R}e_{\text{Avg}}$		$c_{e,\text{Avg}}$ Avg. Test Results	c_e Spline Model
(1/ft)	(1/m)			(1/ft)	(1/m)		
6.572E+04	2.156E+05	0.01227	0.01248	6.604E+04	2.167E+05	0.0001652	0.0001602
8.609E+04	2.825E+05	0.01554	0.01554	8.645E+04	2.836E+05	0.0001972	0.0001971
1.217E+05	3.992E+05	0.02070	0.02048	1.223E+05	4.012E+05	0.0002612	0.0002629
1.490E+05	4.889E+05	0.02381	0.02366	1.498E+05	4.915E+05	0.0003110	0.0003150
1.722E+05	5.651E+05	0.02581	0.02591	1.730E+05	5.676E+05	0.0003562	0.0003603
2.459E+05	8.069E+05	0.03121	0.03122	2.473E+05	8.114E+05	0.0005146	0.0005126
2.981E+05	9.780E+05	0.03388	0.03392	2.997E+05	9.834E+05	0.0006253	0.0006214
4.208E+05	1.380E+06	0.03887	0.03887	4.235E+05	1.390E+06	0.0008696	0.0008716
5.954E+05	1.953E+06	0.04364	0.04364	5.994E+05	1.967E+06	0.0012205	0.0012192
8.589E+05	2.818E+06	0.04864	0.04864	8.638E+05	2.834E+06	0.0017049	0.0017054

Notes: This table provides the average unit Reynolds number, $\hat{R}e_{\text{Avg}}$, and the average effective porosity, $c_{e,\text{Avg}}$. These averages were calculated for each of the ten differential pressures used in the permeability tests. The data in this table are listed in order of increasing $\hat{R}e_{\text{Avg}}$.

4.2 Effective Porosity Modeling

In reference 5, the following equation is proposed to model the relationship between c_e and $\hat{Re}$

$$c_e = \frac{-K_2}{2K_1\hat{Re}} + \sqrt{\left(\frac{K_2}{2K_1\hat{Re}}\right)^2 + \frac{1}{2K_1}} \tag{6}$$

where K_1 and K_2 are constants dependent only on the specific fabric. Nonlinear least-squares fits of the porosity data presented in Appendix C were performed using equation (6). The values of K_1 and K_2 obtained from these fits are given in table 6. The curves created using these fits are presented graphically in figures 5 and 6 as black dashed lines labeled "K_1, K_2 model" (note that in these figures the fits are shown extrapolated for values of $\hat{Re}$ beyond the available porosity test data). As can be seen from figures 5 and 6, equation (6) with appropriate values of K_1 and K_2 provide good fits to the porosity results, except for the lowest values of $\hat{Re}$ for the PIA-C-44378D Type I fabric.

Table 6. Fitted values of K_1 and K_2 for both fabrics.

Fabric	K_1	K_2	
	(dimensionless)	(1/ft)	(1/m)
PIA-C-7020D Type I	1.5881679E+02	2.63019691E+06	8.62925494E+06
PIA-C-44378D Type I	1.1303031E+04	2.37148232E+08	7.78045379E+08

Additional models are shown in figures 5 and 6 and presented numerically in table 5. The values of $c_{e,\text{Avg}}$ and $\hat{Re}_{\text{Avg}}$ in table 5 were used to create spline models. These models attempted to fit the porosity results with a smooth curve that did not necessarily go through each point $(c_{e,\text{Avg}}, \hat{Re}_{\text{Avg}})$. The spline models are shown as solid red lines in figures 5 and 6. These spline models provide an alternative to the "K_1, K_2 model" defined by equation (6) and may be better models to the data in some intervals. Note, however, that the spline models are not suitable for extrapolation to values of $\hat{Re}$ other than those used to create them.

4.3 Effective Porosity Application

The total porosity of the parachute, λ_T, can be calculated using the equation

$$\lambda_T = k\lambda_g + \left(1-\lambda_g\right)c_e \tag{7}$$

where λ_g is the geometric porosity of the parachute, and k is the discharge coefficient with a value somewhere between 0.6 and 0.7.[3] In equation (7), the term $k\lambda_g$ is the contribution of geometric porosity of the parachute to λ_T, and the $(1-\lambda_g)c_e$ term is the contribution due to fabric

[3] From the document by Lingard (ref. 6): "and k the discharge coefficient, typically 0.6 to 0.7. In the literature you will usually find total porosity incorrectly, but simply, defined as $\lambda_T = \lambda_g + c_e$. This fails to allow for the open areas in the material porosity element and assumes perfect discharge."

permeability. To estimate c_e, an appropriate value of $\hat{Re}$ has to be determined for use in the porosity models described in the previous section. Solving equation (2) for U and substituting the result into equation (3) yields

$$\hat{Re} = \frac{\sqrt{2\rho\Delta p}}{\mu} \tag{8}$$

In equation (8), it is assumed that the flight condition is known and, thus, ρ and μ are known. Thus, what remains to be done to calculate $\hat{Re}$ is to determine Δp. Two methods are presented here for calculating Δp. From reference 5:

$$\Delta p = \frac{qC_D S_0}{S_P} \qquad \text{[Method 1]} \tag{9}$$

where q is the dynamic pressure at the flight condition, C_D is the parachute's drag coefficient, S_0 is the parachute's nominal area (used as the reference area for C_D), and S_p is the parachute's inflated projected area. Note that the value of Δp determined by equation (9) is the drag of the parachute, qC_DS_0, divided by the projected area, S_p. A simplified calculation for Δp is

$$\Delta p = q \qquad \text{[Method 2]} \tag{10}$$

The differential pressure yielded by equation (10) is equivalent to assuming that the inside of the canopy is at total pressure and the outside is at freestream static pressure (in incompressible flow).

Both methods yield approximate values of Δp on the parachute's fabric. Method 1 is theoretically more accurate, because it accounts for the relationship between the differential pressure across the fabric and the parachute drag, but it requires knowledge of C_D, S_0, and S_p. Method 2 only requires knowledge of the dynamic pressure at the flight condition.

Results using the equations above are presented in table 7 for two Disk-Gap-Band (DGB) parachutes of nearly identical geometry and tested at essentially the same conditions (i.e., Mach number and dynamic pressure). These DGB parachutes were subscale (6.7 percent) models simulating the Mars Science Laboratory (MSL) descent configuration. They were tested in the NASA Langley Research Center Transonic Dynamics Tunnel as described in reference 1. Each parachute was fabricated using either PIA-C-7020D Type I or PIA-C-44378D Type I fabric. The test condition was selected because it is relevant to Mars-flight operations. A value of $k = 0.7$ was assumed in the calculations. For the parachute fabricated from PIA-C-7020D Type I fabric, the contribution of fabric permeability to the total porosity was significant: $(1 - \lambda_g)c_e/\lambda_T \approx 0.21$. Conversely, for the parachute fabricated from PIA-C-44378D Type I fabric, the contribution of fabric permeability to the total porosity was insignificant: $(1 - \lambda_g)c_e/\lambda_T < 0.005$. Both parachutes had nearly the same geometric porosity. However, the contribution of fabric permeability yielded a large difference in the total porosity, $\lambda_T \approx 0.107$ vs. $\lambda_T \approx 0.084$, for the parachutes fabricated from PIA-C-7020D Type I and PIA-C-44378D Type I fabrics, respectively. In this example the difference between the Method 1 and Method 2 calculations yielded only small differences in c_e and λ_T.

Table 7. Example total porosity calculations for two Disk-Gap-Band parachutes.

Quantity	Units	Parachute Fabric	
		PIA-C-7020D Type I	PIA-C-44378D Type I
S_0	ft^2	17.22	17.44
	m^2	1.600	1.620
S_p	ft^2	9.28	9.40
	m^2	0.862	0.873
S_0 / S_p	-	1.856	1.856
C_D	-	0.583	0.626
$C_D S_0 / S_P$	-	1.083	1.163
q	psf	14.02	14.36
	Pa	671.2	687.7
Δp [Method 1]	psf	15.18	16.70
	Pa	726.9	799.7
Δp [Method 2]	psf	14.02	14.36
	Pa	671.2	687.7
μ	slug/(ft•s)	3.733E-07	3.738E-07
	kg/(m•s)	1.787E-05	1.790E-05
ρ	$slug/ft^3$	1.346E-04	1.365E-04
	kg/m^3	6.938E-02	7.037E-02
$\hat{Re}$ [Method 1]	1/ft	1.713E+05	1.807E+05
	1/m	5.620E+05	5.927E+05
$\hat{Re}$ [Method 2]	1/ft	1.646E+05	1.675E+05
	1/m	5.400E+05	5.497E+05
K_1	-	1.588E+02	1.130E+04
K_2	1/ft	2.630E+06	2.371E+08
	1/m	8.629E+06	7.780E+08
c_e [Method 1]	-	0.02572	0.00038
c_e [Method 2]	-	0.02505	0.00035
k	-	0.7	0.7
λ_g	-	0.1210	0.1197
$k\lambda_g$	-	0.0847	0.0838
$(1 - \lambda_g)c_e$ [Method 1]	-	0.0226	0.0003
$(1 - \lambda_g)c_e$ [Method 2]	-	0.0220	0.0003
λ_T [Method 1]	-	0.1073	0.0841
λ_T [Method 2]	-	0.1067	0.0841
$(1 - \lambda_g)c_e / \lambda_T$ [Method 1]	-	0.2107	0.0040
$(1 - \lambda_g)c_e / \lambda_T$ [Method 2]	-	0.2063	0.0037

Notes: The test Mach numbers were 0.41 for the data shown above. The effective porosities, c_e, were calculated using the "K_1, K_2 model" defined by equation (6) with the values for K_1 and K_2 presented in table 6.

As expected, drag coefficient is affected by the total porosity. The parachute with the lower total porosity ($\lambda_T \approx 0.084$, fabricated from PIA-C-44378 Type I fabric) has a higher drag coefficient, $C_D = 0.626$, than the one with the higher total porosity ($\lambda_T \approx 0.107$ fabricated from PIA-C-7020D Type I fabric), $C_D = 0.583$.

With the calculated values of λ_T, and the known values of C_D at the test condition being considered, an interpolation was constructed to determine an estimated value of C_D at a different flight condition. Based on the data in table 7, the following linear relationships between λ_T and C_D were defined using the data for both parachutes:

$$C_D = C_{0,M1} + C_{1,M1}\lambda_{T,M1} \qquad \text{[Method 1]} \tag{11}$$

$$C_D = C_{0,M2} + C_{1,M2}\lambda_{T,M2} \qquad \text{[Method 2]} \tag{12}$$

Note that the identities of Method 1 and Method 2 were retained in equations (11) and (12), respectively, by specifying different linear constants ($C_{0,M1}$, $C_{1,M1}$) and ($C_{0,M2}$, $C_{1,M2}$). Values for these constants are given in table 8. Note that the linear relationships specified in equations (11) and (12) with the constants shown in table 8 are specific to the example's parachute/payload geometry (MSL) and Mach number (0.41).

Table 8. Values of constants in equations (11) and (12) for the example.

	C_0	C_1
Method 1 (subscript *M*1)	0.782417	–1.85371
Method 2 (subscript *M*2)	0.786256	–1.89989

The next step is to derive equations for the determination of C_D given the flight conditions and the parachute fabric used. Considering Method 1 first, combining equations (11), (7), (6), (8), and (9) yields

$$C_D = C_{0,M1} + C_{1,M1}\left[k\lambda_g + \left(1-\lambda_g\right)\left(\frac{-K_2\mu}{2K_1\sqrt{2\rho\frac{qC_DS_0}{S_p}}} + \sqrt{\frac{\left(K_2\mu\right)^2}{8K_1^2\rho\frac{qC_DS_0}{S_p}} + \frac{1}{2K_1}}\right)\right] \tag{13}$$

Similarly, for Method 2, combining equations (11), (7), (6), (8), and (10) yields

$$C_D = C_{0,M2} + C_{1,M2}\left[k\lambda_g + \left(1-\lambda_g\right)\left(\frac{-K_2\mu}{2K_1\sqrt{2\rho q}} + \sqrt{\frac{\left(K_2\mu\right)^2}{8K_1^2\rho q} + \frac{1}{2K_1}}\right)\right] \tag{14}$$

Several observations can be made regarding equations (13) and (14):

1. The flight parameters needed are q, ρ, and μ.
2. The equations are applicable to essentially the same parachute/payload geometry as that used to determine C_0 and C_1. When using Method 1, *small* differences in λ_g and/or S_0/S_p are taken into consideration. Because the values of λ_g are nearly constant, the sensitivity of C_D to the assumed value of k is small (however, the value of k is subject to the limitation specified in observation 3).
3. The value of k used with these equations has to be the same used in the original determination of λ_T ($k = 0.7$ in the present example).
4. The equations are applicable for parachutes using any fabric material for which K_1 and K_2 are known.
5. Equation (13) [Method 1] is implicit; that is, C_D appears both on the right and left hand sides of the equation. Thus, equation (13) needs to be solved numerically for C_D.
6. Equation (14) [Method 2] is explicit; that is, C_D appears only on the left hand side of the equation. Thus, with Method 2, C_D can be calculated directly using equation (14).

The flight condition shown in table 9 is a reconstructed value of that experienced by MSL during descent on Mars at a Mach number of 0.41. Note that this flight condition occurs in an atmosphere consisting mostly of carbon dioxide. Additional data on the MSL parachute are given in table 10.

Table 9. Conditions experienced by MSL during descent on Mars at a Mach number of 0.41, as obtained from flight reconstruction.

Quantity	Units	Value
q	psf	0.8217
	Pa	39.34
ρ	slug/ft^3	1.627E-05
	kg/m^3	8.384E-03
μ	slug/(ft•s)	2.344E-07
	kg/(m•s)	1.122E-05

Table 10. Additional data on the MSL parachute.

Quantity	Value or Specification	Comment
λ_g	0.1280	Actual. See reference 9. Slightly higher than that for the subscale model parachutes.
S_0 / S_p	1.856	Assumed to be the same as the subscale model parachutes.
Fabric	PIA-C-7020D Type I	Assumed. The actual MSL parachute was mostly fabricated from PIA-C-7020B Type I and PIA-C-7020C Type I fabric. However, a 1.4 oz/yd^2 polyester was used in the crown area. See reference 9.

Applying the data in tables 9 and 10 to equations (13) and (14) yielded the estimates for C_D shown in table 11. Because of the low-density Mars environment and operation at low dynamic pressures, the value of $\hat{Re}$ was very low, in turn yielding low values of c_e and λ_T. The values of C_D obtained in this example were the same for both Methods 1 and 2 for all practical purposes. The value C_D = 0.609 obtained herein is close to the pre-flight estimated nominal C_D value of 0.615 used in the flight mechanics simulations for MSL (see reference. 9). This comparison, however, needs to be considered in light of the differences in fabric materials noted in the "Comments" column of table 10 and the uncertainty bounds on the pre-flight estimated nominal value of C_D namely ±12.5 percent.

Table 11. Drag coefficient interpolation results for the MSL on-Mars flight condition example.

Quantity	Units	Method 1	Method 2
Δp	psf	0.9291	0.8217
	Pa	44.49	39.34
$\hat{Re}$	1/ft	2.346E+04	2.206E+04
	1/m	7.697E+04	7.238E+04
c_e	-	0.0044	0.0042
λ_T	-	0.0935	0.0932
C_D	-	0.609	0.609

5 Concluding Remarks

The fabric permeability data obtained served its principal purpose – to aid in the interpretation and use of parachute data. The expected relationship between total porosity and drag coefficient was confirmed. Combining the effective porosity models (derived from the fabric permeability data) with the wind tunnel test results allowed for an estimation of the drag coefficient of the example parachute system geometry (MSL) operating at the same Mach number on Mars. This estimate of the drag coefficient is close to the nominal pre-flight estimated value, giving credibility to the analysis approach presented in this technical memorandum.

A suggested topic for follow-on research is to verify the assumption that the effective porosity of parachute fabrics can be modeled as a function of unit Reynolds number, *independent of the upstream pressure, p, at which the test is conducted*, and *independent of the gas used for testing*. Note that the pressure- and gas-independence assumptions were made in the final set of calculations for the example; the effective porosity of the fabrics were determined in air at ambient upstream pressure, and these data were used in calculations for Mars' low-pressure carbon dioxide atmosphere.

6 References

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Appendix A Permeability Test Results

Table A1. Permeability results for PIA-C-7020D Type I fabric in chronological testing order.

Sample	Date	Time (PST)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δ*p*		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
1	1/21/16	11:13	28.00	1980	94819	71.8	531.5	295.3	34.2	0.146	7.0	9.06	4.60
1	1/21/16	11:17	28.00	1980	94819	72.1	531.8	295.4	34.2	0.251	12.0	14.76	7.50
1	1/21/16	11:23	28.00	1980	94819	72.3	532.0	295.5	34.2	0.501	24.0	27.17	13.80
1	1/21/16	11:28	27.99	1980	94785	72.4	532.1	295.6	35.3	0.752	36.0	37.80	19.20
1	1/21/16	11:33	27.99	1980	94785	72.7	532.4	295.8	33.7	1.003	48.0	47.44	24.10
1	1/21/16	11:38	27.99	1980	94785	72.8	532.5	295.8	33.7	2.047	98.0	81.50	41.40
1	1/21/16	11:42	27.99	1980	94785	73.0	532.7	295.9	33.7	3.008	144.0	107.87	54.80
1	1/21/16	11:47	27.99	1980	94785	73.1	532.8	296.0	33.1	5.994	287.0	174.41	88.60
1	1/21/16	11:51	27.99	1980	94785	73.2	532.9	296.0	33.1	12.009	575.0	275.59	140.00
1	1/21/16	11:56	27.98	1979	94751	73.4	533.1	296.2	33.3	25.000	1197.0	444.88	226.00
1	1/21/16	12:00	27.97	1978	94717	73.5	533.2	296.2	33.1	0.146	7.0	8.94	4.54
2	1/21/16	12:02	27.97	1978	94717	73.6	533.3	296.3	33.2	0.146	7.0	7.95	4.04
2	1/21/16	12:06	27.97	1978	94717	73.6	533.3	296.3	33.2	1.003	48.0	43.31	22.00
2	1/21/16	12:10	27.97	1978	94717	73.7	533.4	296.3	33.2	3.008	144.0	98.82	50.20
2	1/21/16	12:14	27.97	1978	94717	73.9	533.6	296.4	33.2	0.251	12.0	13.13	6.67
2	1/21/16	12:19	27.96	1978	94683	73.9	533.6	296.4	33.2	0.501	24.0	24.61	12.50
2	1/21/16	12:23	27.96	1978	94683	73.9	533.6	296.4	33.0	5.994	287.0	160.83	81.70
2	1/21/16	12:26	27.95	1977	94650	74.0	533.7	296.5	33.2	25.000	1197.0	411.42	209.00
2	1/21/16	12:30	27.95	1977	94650	74.1	533.8	296.5	32.9	12.009	575.0	259.84	132.00
2	1/21/16	12:34	27.95	1977	94650	74.1	533.8	296.5	32.6	0.752	36.0	35.43	18.00
2	1/21/16	12:38	27.95	1977	94650	74.1	533.8	296.5	32.5	2.047	98.0	76.77	39.00
2	1/21/16	12:42	27.95	1977	94650	74.3	534.0	296.7	32.6	0.146	7.0	8.11	4.12

Table A1. Permeability results for PIA-C-7020D Type I fabric in chronological testing order. Concluded.

Sample	Date	Time (PST)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	(ft^3/ft^2/min)	(cm^3/cm^2/s)
3	1/21/16	12:47	27.95	1977	94650	74.3	534.0	296.7	32.1	0.146	7.0	8.50	4.32
3	1/21/16	12:52	27.94	1976	94616	74.1	533.8	296.5	32.1	0.251	12.0	14.09	7.16
3	1/21/16	12:56	27.94	1976	94616	74.1	533.8	296.5	32.2	2.047	98.0	81.50	41.40
3	1/21/16	13:01	27.94	1976	94616	74.2	533.9	296.6	32.1	12.009	575.0	277.56	141.00
3	1/21/16	13:05	27.94	1976	94616	74.2	533.9	296.6	32.1	5.994	287.0	175.39	89.10
3	1/21/16	13:08	27.94	1976	94616	74.2	533.9	296.6	32.1	0.752	36.0	37.99	19.30
3	1/21/16	13:13	27.93	1975	94582	74.3	534.0	296.7	32.1	25.000	1197.0	452.76	230.00
3	1/21/16	13:16	27.93	1975	94582	74.3	534.0	296.7	31.9	1.003	48.0	48.23	24.50
3	1/21/16	13:20	27.93	1975	94582	74.4	534.1	296.7	31.6	0.501	24.0	27.17	13.80
3	1/21/16	13:24	27.93	1975	94582	74.4	534.1	296.7	31.2	3.008	144.0	109.45	55.60
3	1/21/16	13:27	27.93	1975	94582	74.4	534.1	296.7	30.9	0.146	7.0	8.48	4.31
4	1/21/16	13:30	27.93	1975	94582	74.4	534.1	296.7	30.9	0.146	7.0	8.01	4.07
4	1/21/16	13:34	27.92	1975	94548	74.5	534.2	296.8	30.9	3.008	144.0	103.15	52.40
4	1/21/16	13:37	27.92	1975	94548	74.6	534.3	296.8	32.6	1.003	48.0	45.28	23.00
4	1/21/16	13:41	27.92	1975	94548	74.6	534.3	296.8	30.9	25.000	1197.0	427.17	217.00
4	1/21/16	13:45	27.92	1975	94548	74.6	534.3	296.8	30.9	2.047	98.0	79.13	40.20
4	1/21/16	13:49	27.92	1975	94548	74.7	534.4	296.9	30.3	0.251	12.0	13.52	6.87
4	1/21/16	13:53	27.92	1975	94548	74.7	534.4	296.9	29.8	5.994	287.0	168.70	85.70
4	1/21/16	13:57	27.92	1975	94548	74.9	534.6	297.0	29.8	0.752	36.0	36.42	18.50
4	1/21/16	14:01	27.90	1973	94480	74.9	534.6	297.0	29.8	0.501	24.0	25.79	13.10
4	1/21/16	14:05	27.91	1974	94514	75.0	534.7	297.0	29.8	12.009	575.0	267.72	136.00
4	1/21/16	14:08	27.91	1974	94514	74.9	534.6	297.0	29.8	0.146	7.0	8.09	4.11
5	1/21/16	14:10	27.91	1974	94514	74.8	534.5	296.9	29.8	0.146	7.0	9.19	4.67
5	1/21/16	14:14	27.91	1974	94514	74.9	534.6	297.0	29.8	0.251	12.0	15.55	7.90
5	1/21/16	14:19	27.91	1974	94514	75.0	534.7	297.0	29.3	0.501	24.0	29.13	14.80
5	1/21/16	14:22	27.91	1974	94514	75.2	534.9	297.2	29.2	0.752	36.0	40.94	20.80
5	1/21/16	14:25	27.92	1975	94548	73.6	533.3	296.3	28.5	1.003	48.0	51.77	26.30
5	1/21/16	14:28	27.91	1974	94514	74.6	534.3	296.8	29.0	2.047	98.0	88.98	45.20
5	1/21/16	14:33	27.91	1974	94514	74.8	534.5	296.9	28.6	3.008	144.0	117.52	59.70
5	1/21/16	14:37	27.91	1974	94514	74.9	534.6	297.0	28.6	5.994	287.0	190.16	96.60
5	1/21/16	14:40	27.91	1974	94514	74.9	534.6	297.0	28.1	12.009	575.0	301.18	153.00
5	1/21/16	14:44	27.91	1974	94514	75.2	534.9	297.2	28.1	25.000	1197.0	486.22	247.00
5	1/21/16	14:48	27.91	1974	94514	74.9	534.6	297.0	28.6	0.146	7.0	9.41	4.78

Table A2. Permeability results for PIA-C-44378D Type I fabric in chronological testing order.

Sample	Date	Time (PST)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	(ft^3/ft^2/min)	(cm^3/cm^2/s)
1	1/22/16	6:49	27.87	1971	94379	72.4	532.1	295.6	26.1	0.146	7.0	0.1211	0.0615
1	1/22/16	6:53	27.87	1971	94379	72.6	532.3	295.7	26.1	0.251	12.0	0.1894	0.0962
1	1/22/16	6:57	27.87	1971	94379	72.6	532.3	295.7	25.2	0.501	24.0	0.3445	0.1750
1	1/22/16	7:01	27.87	1971	94379	72.1	531.8	295.4	25.8	0.752	36.0	0.5157	0.2620
1	1/22/16	7:05	27.87	1971	94379	71.5	531.2	295.1	26.0	1.003	48.0	0.6811	0.3460
1	1/22/16	7:09	27.87	1971	94379	71.1	530.8	294.9	26.0	2.047	98.0	1.4016	0.7120
1	1/22/16	7:13	27.87	1971	94379	70.5	530.2	294.5	26.6	3.008	144.0	2.0669	1.0500
1	1/22/16	7:18	27.87	1971	94379	70.3	530.0	294.4	27.2	5.994	287.0	3.9764	2.0200
1	1/22/16	7:22	27.87	1971	94379	70.0	529.7	294.3	27.2	12.009	575.0	7.9528	4.0400
1	1/22/16	7:26	27.87	1971	94379	69.7	529.4	294.1	27.2	25.000	1197.0	16.2205	8.2400
1	1/22/16	7:30	27.87	1971	94379	69.5	529.2	294.0	27.1	0.146	7.0	0.1197	0.0608
2	1/22/16	12:42	27.79	1965	94108	72.4	532.1	295.6	28.5	0.146	7.0	0.1350	0.0686
2	1/22/16	12:46	27.79	1965	94108	72.5	532.2	295.7	28.5	1.003	48.0	0.7638	0.3880
2	1/22/16	12:50	27.79	1965	94108	72.6	532.3	295.7	28.5	3.008	144.0	2.3425	1.1900
2	1/22/16	12:54	27.79	1965	94108	72.6	532.3	295.7	28.3	0.251	12.0	0.2067	0.1050
2	1/22/16	12:58	27.79	1965	94108	72.5	532.2	295.7	27.9	0.501	24.0	0.3858	0.1960
2	1/22/16	13:03	27.79	1965	94108	72.6	532.3	295.7	28.5	5.994	287.0	4.5669	2.3200
2	1/22/16	13:07	27.78	1965	94074	72.6	532.3	295.7	28.5	25.000	1197.0	18.1102	9.2000
2	1/22/16	13:13	27.78	1965	94074	72.6	532.3	295.7	28.5	12.009	575.0	9.1535	4.6500
2	1/22/16	13:18	27.78	1965	94074	72.6	532.3	295.7	28.5	0.752	36.0	0.5846	0.2970
2	1/22/16	13:22	27.78	1965	94074	72.6	532.3	295.7	28.5	2.047	98.0	1.5965	0.8110
2	1/22/16	13:26	27.78	1965	94074	72.6	532.3	295.7	28.5	0.146	7.0	0.1307	0.0664

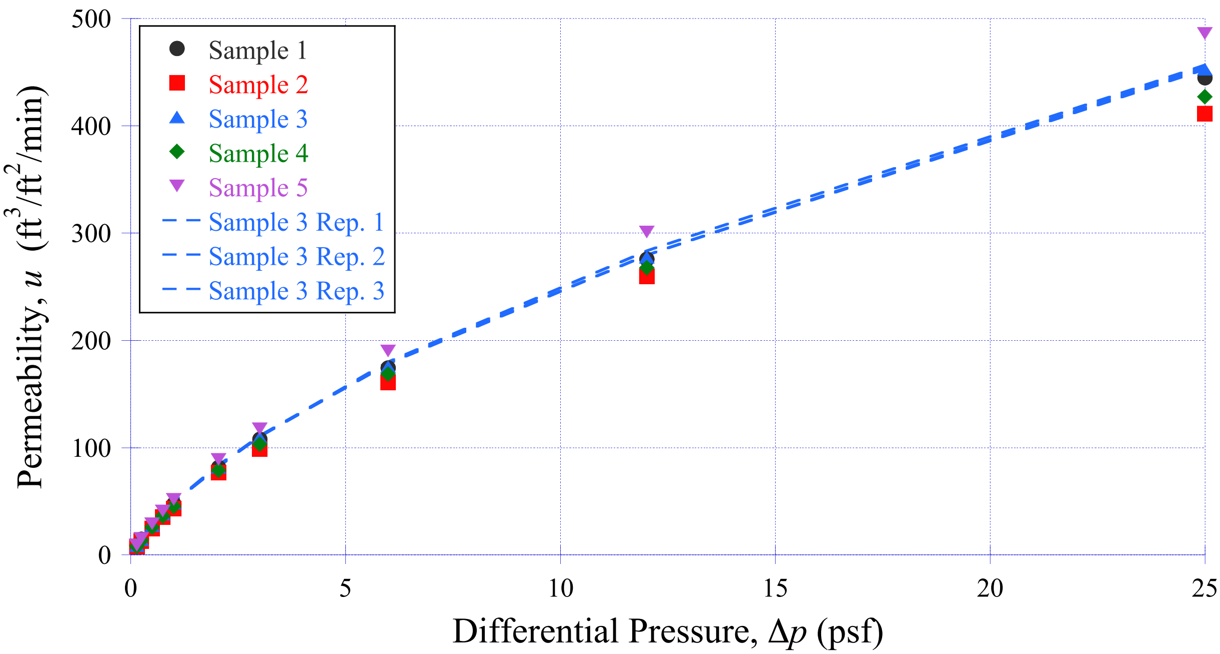
Table A2. Permeability results for PIA-C-44378D Type I fabric in chronological testing order. Concluded.

Sample	Date	Time (PST)	Atmospheric Pressure, p			Temperature, T			Relative Humidity, RH	Differential Pressure, Δp		Permeability, u	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
3	1/22/16	13:27	27.78	1965	94074	72.6	532.3	295.7	28.5	0.146	7.0	0.1106	0.0562
3	1/22/16	13:32	27.77	1964	94040	72.7	532.4	295.8	28.5	0.251	12.0	0.1752	0.0890
3	1/22/16	13:37	27.77	1964	94040	72.7	532.4	295.8	28.5	2.047	98.0	1.2992	0.6600
3	1/22/16	13:40	27.77	1964	94040	72.8	532.5	295.8	28.5	12.009	575.0	7.3819	3.7500
3	1/22/16	13:43	27.77	1964	94040	72.7	532.4	295.8	28.5	5.994	287.0	3.7992	1.9300
3	1/22/16	13:47	27.77	1964	94040	72.8	532.5	295.8	28.5	0.752	36.0	0.4764	0.2420
3	1/22/16	13:51	27.76	1963	94006	72.8	532.5	295.8	28.2	25.000	1197.0	14.8425	7.5400
3	1/22/16	13:55	27.76	1963	94006	72.8	532.5	295.8	27.9	1.003	48.0	0.6457	0.3280
3	1/22/16	13:59	27.76	1963	94006	72.8	532.5	295.8	27.9	0.501	24.0	0.3406	0.1730
3	1/22/16	14:03	27.77	1964	94040	72.9	532.6	295.9	27.6	3.008	144.0	1.9626	0.9970
3	1/22/16	14:07	27.76	1963	94006	72.8	532.5	295.8	27.3	0.146	7.0	0.1128	0.0573
4	1/25/16	5:21	27.81	1967	94175	70.8	530.5	294.7	24.2	0.146	7.0	0.1079	0.0548
4	1/25/16	5:25	27.81	1967	94175	70.8	530.5	294.7	24.4	3.008	144.0	1.7697	0.8990
4	1/25/16	5:29	27.82	1968	94209	70.2	529.9	294.4	24.8	1.003	48.0	0.5866	0.2980
4	1/25/16	5:33	27.82	1968	94209	70.0	529.7	294.3	24.8	25.000	1197.0	14.2126	7.2200
4	1/25/16	5:37	27.82	1968	94209	69.9	529.6	294.2	24.8	2.047	98.0	1.2343	0.6270
4	1/25/16	5:40	27.82	1968	94209	69.5	529.2	294.0	24.8	0.251	12.0	0.1683	0.0855
4	1/25/16	5:44	27.82	1968	94209	69.5	529.2	294.0	24.8	5.994	287.0	3.5827	1.8200
4	1/25/16	5:48	27.82	1968	94209	69.4	529.1	293.9	24.8	0.752	36.0	0.4508	0.2290
4	1/25/16	5:52	27.82	1968	94209	69.2	528.9	293.8	24.8	0.501	24.0	0.3209	0.1630
4	1/25/16	5:56	27.82	1968	94209	69.0	528.7	293.7	24.5	12.009	575.0	7.1260	3.6200
4	1/25/16	6:00	27.82	1968	94209	68.7	528.4	293.5	23.6	0.146	7.0	0.1063	0.0540
5	1/25/16	6:01	27.82	1968	94209	68.7	528.4	293.5	24.7	0.146	7.0	0.1033	0.0525
5	1/25/16	6:04	27.82	1968	94209	68.6	528.3	293.5	24.7	0.251	12.0	0.1618	0.0822
5	1/25/16	6:08	27.83	1968	94243	68.4	528.1	293.4	24.7	0.501	24.0	0.2972	0.1510
5	1/25/16	6:12	27.83	1968	94243	68.0	527.7	293.2	24.7	0.752	36.0	0.4350	0.2210
5	1/25/16	6:16	27.83	1968	94243	67.7	527.4	293.0	24.7	1.003	48.0	0.5787	0.2940
5	1/25/16	6:20	27.83	1968	94243	67.5	527.2	292.9	25.3	2.047	98.0	1.1890	0.6040
5	1/25/16	6:24	27.83	1968	94243	67.4	527.1	292.8	25.3	3.008	144.0	1.7579	0.8930
5	1/25/16	6:28	27.83	1968	94243	67.2	526.9	292.7	25.7	5.994	287.0	3.5039	1.7800
5	1/25/16	6:32	27.83	1968	94243	68.1	527.8	293.2	24.7	12.009	575.0	6.9882	3.5500
5	1/25/16	6:36	27.82	1968	94209	69.7	529.4	294.1	24.5	25.000	1197.0	14.4488	7.3400
5	1/25/16	6:40	27.82	1968	94209	70.5	530.2	294.5	23.6	0.146	7.0	0.1065	0.0541

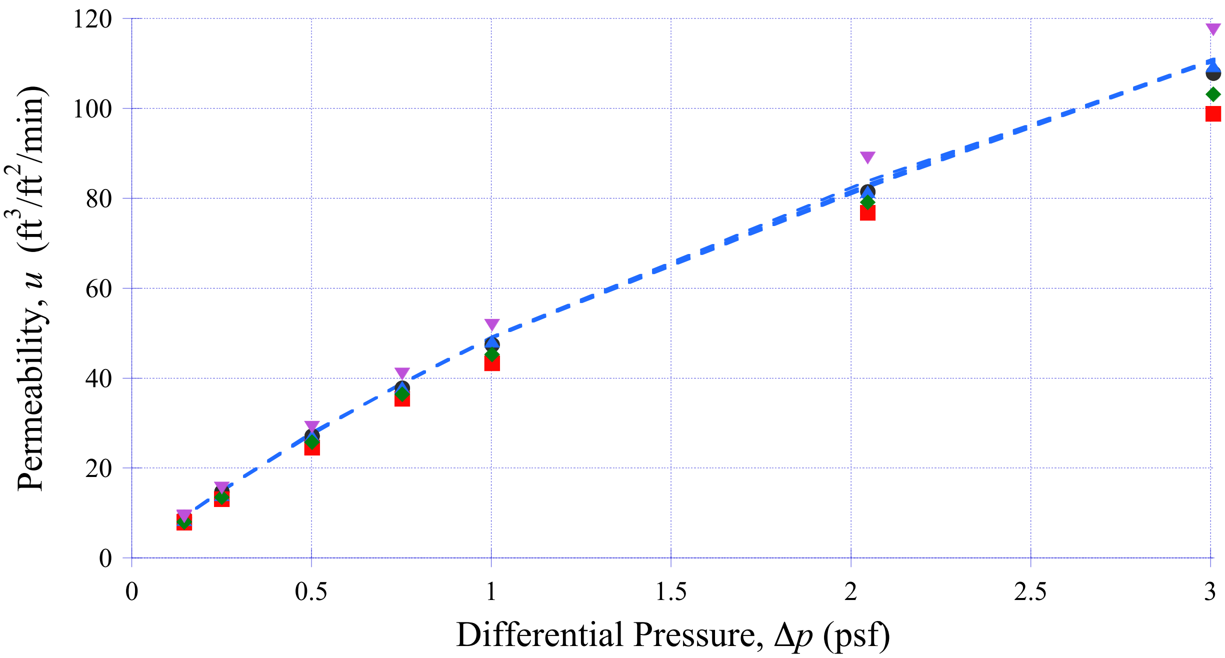
Appendix B Replicate Permeability Test Results

Replicate permeability tests were conducted to evaluate the test-to-test contribution to the variation in the permeability results. Sample 3 of the PIA-C-7020D Type I fabric was retested three times (replicates 1–3), using its corresponding test sequence as shown in table 2. Samples 3 and 4 of the PIA-C-44378D Type I fabric were retested three times each (replicates 1–3), using their corresponding test sequences as shown in table 2. The samples were reset in the instrument between replicate tests. The results of the original tests (symbols), and the replicate tests (interpolated lines) are shown in Figure B1 and Figure B2. The replicate tests' data are presented numerically in Table B1 and Table B2. From these figures and tables it was observed that the test-to-test contribution to the variation observed in the original results was relatively small as compared to the sample-to-sample variation.

For Sample 3, most replicate results (blue dashed lines) using the PIA-C-7020D Type I and PIA-C-44378D Type I fabrics were within 4.8 percent of the values obtained in the original tests (symbol ▲). (All comparisons in this paragraph used the average of the results for a given differential pressure. Percent comparisons used the original results as the baseline.) The two exceptions to this were the results for the two lowest differential pressure values, 0.146 psf (7 Pa) and 0.251 psf (12 Pa) using the PIA-C-7020D Type I fabric; the difference between the original and replicate results were 8.8 and 6.2 percent, respectively. For Sample 4 using the PIA-C-44378D Type I fabric, replicate results (green dotted lines) were within 6.7 percent of those obtained in the original tests (symbol ◆).

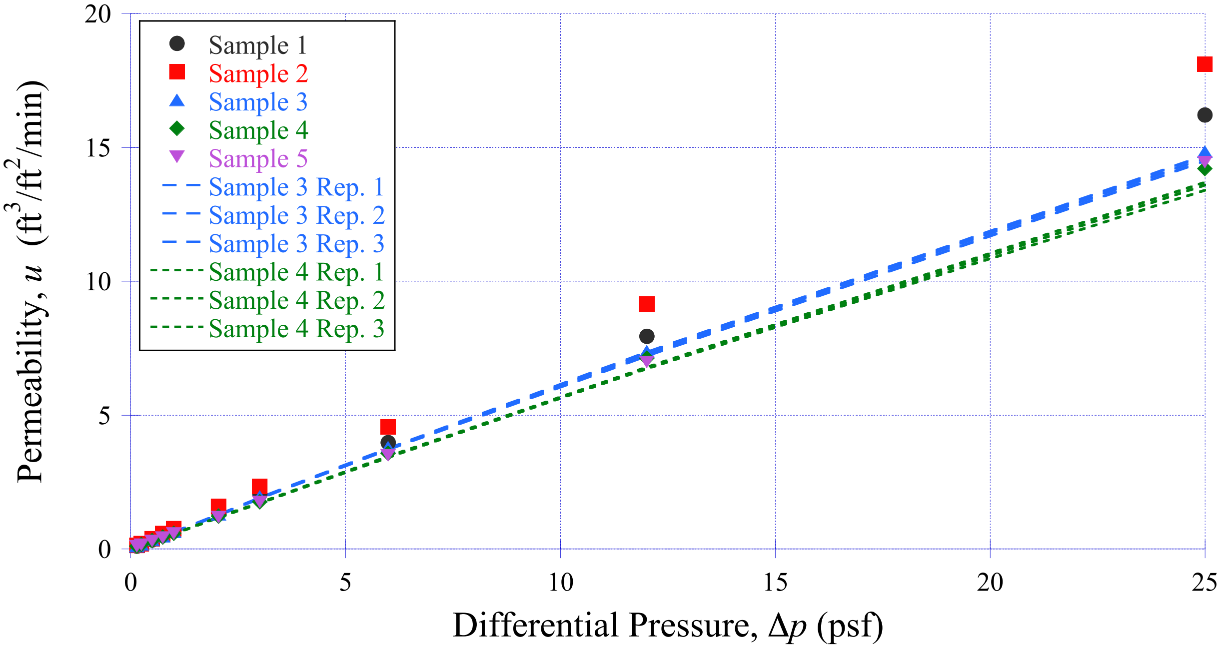


(a) Full differential pressure range: 0.146–25 psf (7–1197 Pa).

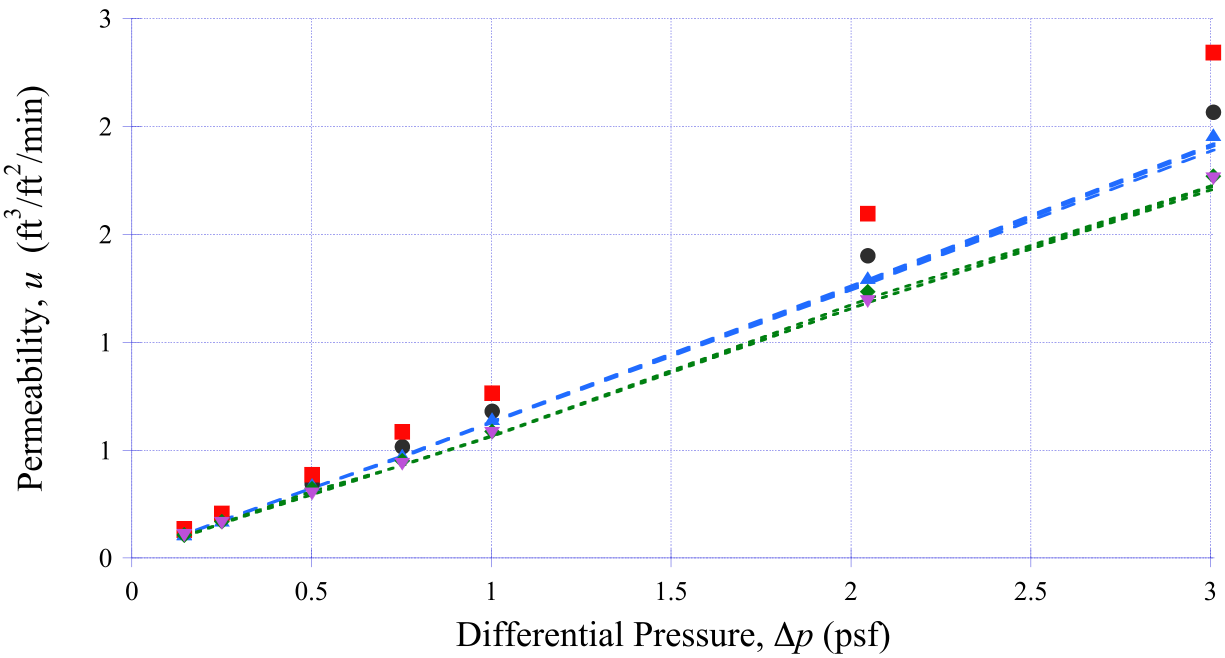


(b) Close up of the lower differential pressure range: 0.146–3 psf (7–143.6 Pa).

Figure B1. Original and replicate permeability results for PIA-C-7020D Type I fabric.



(a) Full differential pressure range: 0.146 to 25 psf (7 to 1197 Pa).



(b) Close up of the lower differential pressure range: 0.146–3 psf (7–143.6 Pa).

Figure B2. Original and replicate permeability results for PIA-C-44378D Type I fabric.

Table B1. Replicate permeability results for PIA-C-7020D Type I fabric in chronological testing order.

Sample/ Replicate	Date	Time (PST)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
3/1	3/3/16	5:21	27.68	1958	93735	69.5	529.2	294.0	17.7	0.146	7.0	9.27	4.71
3/1	3/3/16	5:25	27.68	1958	93735	69.4	529.1	293.9	17.7	0.251	12.0	14.88	7.56
3/1	3/3/16	5:29	27.68	1958	93735	69.2	528.9	293.8	17.7	2.047	98.0	82.48	41.90
3/1	3/3/16	5:33	27.68	1958	93735	69.2	528.9	293.8	17.7	12.009	575.0	279.53	142.00
3/1	3/3/16	5:36	27.68	1958	93735	69.2	528.9	293.8	17.7	5.994	287.0	178.15	90.50
3/1	3/3/16	5:40	27.68	1958	93735	69.2	528.9	293.8	17.7	0.752	36.0	38.78	19.70
3/1	3/3/16	5:44	27.68	1958	93735	69.2	528.9	293.8	17.3	25.000	1197.0	454.72	231.00
3/1	3/3/16	5:48	27.68	1958	93735	69.3	529.0	293.9	17.4	1.003	48.0	49.02	24.90
3/1	3/3/16	5:52	27.68	1958	93735	69.4	529.1	293.9	17.1	0.501	24.0	27.95	14.20
3/1	3/3/16	5:56	27.69	1958	93769	69.3	529.0	293.9	17.1	3.008	144.0	110.63	56.20
3/1	3/3/16	6:00	27.69	1958	93769	69.4	529.1	293.9	17.1	0.146	7.0	9.29	4.72
3/2	3/3/16	6:04	27.69	1958	93769	70.0	529.7	294.3	16.6	0.146	7.0	9.27	4.71
3/2	3/3/16	6:08	27.69	1958	93769	70.8	530.5	294.7	17.3	0.251	12.0	15.06	7.65
3/2	3/3/16	6:12	27.69	1958	93769	72.3	532.0	295.5	15.5	2.047	98.0	83.07	42.20
3/2	3/3/16	6:16	27.69	1958	93769	72.5	532.2	295.7	15.5	12.009	575.0	279.53	142.00
3/2	3/3/16	6:20	27.69	1958	93769	72.2	531.9	295.5	15.6	5.994	287.0	178.74	90.80
3/2	3/3/16	6:24	27.69	1958	93769	71.8	531.5	295.3	16.5	0.752	36.0	38.78	19.70
3/2	3/3/16	6:28	27.69	1958	93769	71.7	531.4	295.2	16.6	25.000	1197.0	452.76	230.00
3/2	3/3/16	6:32	27.69	1958	93769	71.4	531.1	295.0	16.6	1.003	48.0	49.02	24.90
3/2	3/3/16	6:36	27.69	1958	93769	71.3	531.0	295.0	16.6	0.501	24.0	27.76	14.10
3/2	3/3/16	6:40	27.69	1958	93769	71.2	530.9	294.9	16.6	3.008	144.0	111.02	56.40
3/2	3/3/16	6:44	27.69	1958	93769	71.1	530.8	294.9	16.6	0.146	7.0	9.23	4.69
3/3	3/3/16	6:48	27.69	1958	93769	71.2	530.9	294.9	16.6	0.146	7.0	9.21	4.68
3/3	3/3/16	6:52	27.70	1959	93803	71.2	530.9	294.9	16.6	0.251	12.0	14.96	7.60
3/3	3/3/16	6:56	27.70	1959	93803	71.1	530.8	294.9	16.6	2.047	98.0	83.86	42.60
3/3	3/3/16	7:00	27.70	1959	93803	71.1	530.8	294.9	16.6	12.009	575.0	283.46	144.00
3/3	3/3/16	7:05	27.70	1959	93803	71.0	530.7	294.8	16.6	5.994	287.0	179.92	91.40
3/3	3/3/16	7:09	27.70	1959	93803	71.0	530.7	294.8	16.6	0.752	36.0	38.98	19.80
3/3	3/3/16	7:13	27.70	1959	93803	71.0	530.7	294.8	16.6	25.000	1197.0	456.69	232.00
3/3	3/3/16	7:17	27.71	1960	93837	71.0	530.7	294.8	16.6	1.003	48.0	49.21	25.00
3/3	3/3/16	7:21	27.70	1959	93803	70.9	530.6	294.8	16.6	0.501	24.0	27.56	14.00
3/3	3/3/16	7:26	27.71	1960	93837	70.9	530.6	294.8	16.6	3.008	144.0	110.43	56.10
3/3	3/3/16	7:30	27.70	1959	93803	70.9	530.6	294.8	16.6	0.146	7.0	9.17	4.66

Table B2. Replicate permeability results for PIA-C-44378D Type I fabric in chronological testing order.

Sample/ Replicate	Date	Time (PST)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
3/1	2/29/16	6:09	27.73	1961	93905	72.7	532.4	295.8	26.1	0.146	7.0	0.1090	0.0554
3/1	2/29/16	6:14	27.74	1962	93938	72.5	532.2	295.7	26.1	0.251	12.0	0.1730	0.0879
3/1	2/29/16	6:18	27.74	1962	93938	72.3	532.0	295.5	26.1	2.047	98.0	1.2700	0.6452
3/1	2/29/16	6:22	27.74	1962	93938	72.3	532.0	295.5	26.5	12.009	575.0	7.2100	3.6627
3/1	2/29/16	6:26	27.74	1962	93938	72.2	531.9	295.5	26.7	5.994	287.0	3.7200	1.8898
3/1	2/29/16	6:30	27.75	1963	93972	72.1	531.8	295.4	27.3	0.752	36.0	0.4660	0.2367
3/1	2/29/16	6:34	27.74	1962	93938	72.0	531.7	295.4	27.3	25.000	1197.0	14.5000	7.3660
3/1	2/29/16	6:38	27.75	1963	93972	71.9	531.6	295.3	27.3	1.003	48.0	0.6280	0.3190
3/1	2/29/16	6:42	27.75	1963	93972	71.8	531.5	295.3	27.3	0.501	24.0	0.3240	0.1646
3/1	2/29/16	6:46	27.74	1962	93938	71.8	531.5	295.3	27.3	3.008	144.0	1.8900	0.9601
3/1	2/29/16	6:50	27.74	1962	93938	71.8	531.5	295.3	27.3	0.146	7.0	0.1090	0.0554
3/2	2/29/16	6:56	27.74	1962	93938	71.7	531.4	295.2	27.3	0.146	7.0	0.1100	0.0559
3/2	2/29/16	6:59	27.75	1963	93972	71.7	531.4	295.2	27.3	0.251	12.0	0.1750	0.0889
3/2	2/29/16	7:04	27.74	1962	93938	71.8	531.5	295.3	27.3	2.047	98.0	1.2800	0.6502
3/2	2/29/16	7:08	27.75	1963	93972	71.8	531.5	295.3	27.3	12.009	575.0	7.2900	3.7033
3/2	2/29/16	7:12	27.76	1963	94006	71.8	531.5	295.3	27.3	5.994	287.0	3.7500	1.9050
3/2	2/29/16	7:16	27.75	1963	93972	71.8	531.5	295.3	27.3	0.752	36.0	0.4730	0.2403
3/2	2/29/16	7:20	27.76	1963	94006	71.7	531.4	295.2	27.7	25.000	1197.0	14.6000	7.4168
3/2	2/29/16	7:24	27.76	1963	94006	71.7	531.4	295.2	27.8	1.003	48.0	0.6320	0.3211
3/2	2/29/16	7:28	27.76	1963	94006	71.7	531.4	295.2	27.8	0.501	24.0	0.3250	0.1651
3/2	2/29/16	7:32	27.77	1964	94040	71.6	531.3	295.2	27.8	3.008	144.0	1.9100	0.9703
3/2	2/29/16	7:37	27.76	1963	94006	71.6	531.3	295.2	27.8	0.146	7.0	0.1100	0.0559
3/3	2/29/16	7:41	27.77	1964	94040	71.6	531.3	295.2	28.3	0.146	7.0	0.1100	0.0559
3/3	2/29/16	7:45	27.77	1964	94040	71.6	531.3	295.2	28.4	0.251	12.0	0.1700	0.0864
3/3	2/29/16	7:49	27.77	1964	94040	71.6	531.3	295.2	28.4	2.047	98.0	1.2900	0.6553
3/3	2/29/16	7:53	27.77	1964	94040	71.6	531.3	295.2	28.4	12.009	575.0	7.3500	3.7338
3/3	2/29/16	7:57	27.77	1964	94040	71.7	531.4	295.2	28.4	5.994	287.0	3.7600	1.9101
3/3	2/29/16	8:01	27.77	1964	94040	71.7	531.4	295.2	28.4	0.752	36.0	0.4690	0.2383
3/3	2/29/16	8:05	27.77	1964	94040	71.8	531.5	295.3	28.3	25.000	1197.0	14.7000	7.4676
3/3	2/29/16	8:10	27.77	1964	94040	71.9	531.6	295.3	28.4	1.003	48.0	0.6330	0.3216
3/3	2/29/16	8:15	27.77	1964	94040	72.0	531.7	295.4	28.2	0.501	24.0	0.3240	0.1646
3/3	2/29/16	8:20	27.77	1964	94040	72.1	531.8	295.4	28.4	3.008	144.0	1.9200	0.9754
3/3	2/29/16	8:24	27.78	1965	94074	72.1	531.8	295.4	28.3	0.146	7.0	0.1090	0.0554

Table B2. Replicate permeability results for PIA-C-44378D Type I fabric in chronological testing order. Concluded.

Sample/ Replicate	Date	Time (PST)	Atmospheric Pressure, p			Temperature, T			Relative Humidity, RH	Differential Pressure, Δp		Permeability, u	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
4/1	3/3/16	7:43	27.71	1960	93837	71.0	530.7	294.8	16.6	0.146	7.0	0.0996	0.0506
4/1	3/3/16	7:48	27.71	1960	93837	71.0	530.7	294.8	16.6	3.008	144.0	1.7087	0.8680
4/1	3/3/16	7:52	27.71	1960	93837	71.1	530.8	294.9	16.6	1.003	48.0	0.5630	0.2860
4/1	3/3/16	7:56	27.71	1960	93837	71.1	530.8	294.9	16.6	25.000	1197.0	13.4055	6.8100
4/1	3/3/16	8:00	27.71	1960	93837	71.1	530.8	294.9	16.6	2.047	98.0	1.1831	0.6010
4/1	3/3/16	8:04	27.71	1960	93837	71.1	530.8	294.9	16.6	0.251	12.0	0.1614	0.0820
4/1	3/3/16	8:08	27.71	1960	93837	71.2	530.9	294.9	16.6	5.994	287.0	3.4252	1.7400
4/1	3/3/16	8:12	27.72	1961	93871	71.3	531.0	295.0	16.6	0.752	36.0	0.4291	0.2180
4/1	3/3/16	8:16	27.72	1961	93871	71.4	531.1	295.0	16.6	0.501	24.0	0.3091	0.1570
4/1	3/3/16	8:21	27.72	1961	93871	71.5	531.2	295.1	16.6	12.009	575.0	6.7323	3.4200
4/1	3/3/16	8:25	27.72	1961	93871	71.6	531.3	295.2	16.6	0.146	7.0	0.1006	0.0511
4/2	3/3/16	8:30	27.72	1961	93871	71.7	531.4	295.2	16.6	0.146	7.0	0.1004	0.0510
4/2	3/3/16	8:35	27.72	1961	93871	71.8	531.5	295.3	16.6	3.008	144.0	1.7224	0.8750
4/2	3/3/16	8:39	27.72	1961	93871	71.9	531.6	295.3	16.6	1.003	48.0	0.5669	0.2880
4/2	3/3/16	8:43	27.72	1961	93871	72.1	531.8	295.4	16.6	25.000	1197.0	13.6024	6.9100
4/2	3/3/16	8:47	27.72	1961	93871	72.1	531.8	295.4	16.6	2.047	98.0	1.1831	0.6010
4/2	3/3/16	8:52	27.72	1961	93871	72.1	531.8	295.4	16.6	0.251	12.0	0.1596	0.0811
4/2	3/3/16	8:56	27.72	1961	93871	72.3	532.0	295.5	16.6	5.994	287.0	3.4252	1.7400
4/2	3/3/16	9:01	27.72	1961	93871	72.3	532.0	295.5	16.6	0.752	36.0	0.4311	0.2190
4/2	3/3/16	9:05	27.72	1961	93871	72.4	532.1	295.6	16.6	0.501	24.0	0.2933	0.1490
4/2	3/3/16	9:09	27.72	1961	93871	72.5	532.2	295.7	16.6	12.009	575.0	6.7520	3.4300
4/2	3/3/16	9:13	27.72	1961	93871	72.6	532.3	295.7	16.6	0.146	7.0	0.0992	0.0504
4/3	3/3/16	9:22	27.72	1961	93871	72.9	532.6	295.9	15.5	0.146	7.0	0.1000	0.0508
4/3	3/3/16	9:26	27.72	1961	93871	73.0	532.7	295.9	15.5	3.008	144.0	1.7283	0.8780
4/3	3/3/16	9:30	27.72	1961	93871	73.2	532.9	296.0	15.5	1.003	48.0	0.5650	0.2870
4/3	3/3/16	9:34	27.71	1960	93837	71.1	530.8	294.9	16.6	25.000	1197.0	13.7008	6.9600
4/3	3/3/16	9:38	27.72	1961	93871	69.0	528.7	293.7	17.7	2.047	98.0	1.2008	0.6100
4/3	3/3/16	9:42	27.72	1961	93871	68.0	527.7	293.2	18.7	0.251	12.0	0.1610	0.0818
4/3	3/3/16	9:46	27.72	1961	93871	69.4	529.1	293.9	17.7	5.994	287.0	3.4646	1.7600
4/3	3/3/16	9:51	27.72	1961	93871	70.5	530.2	294.5	16.6	0.752	36.0	0.4311	0.2190
4/3	3/3/16	9:55	27.72	1961	93871	71.2	530.9	294.9	16.6	0.501	24.0	0.2953	0.1500
4/3	3/3/16	10:00	27.72	1961	93871	72.1	531.8	295.4	15.5	12.009	575.0	6.7913	3.4500
4/3	3/3/16	10:04	27.72	1961	93871	72.2	531.9	295.5	15.5	0.146	7.0	0.1022	0.0519

Appendix C Effective Porosity Test Results

Table C1. Effective porosity results for PIA-C-7020D Type I fabric.

$\hat{R}e$		c_e	$\hat{R}e$		c_e
(1/ft)	(1/m)		(1/ft)	(1/m)	
6.556E+04	2.151E+05	0.01157	1.724E+05	5.656E+05	0.02370
6.556E+04	2.151E+05	0.01345	1.728E+05	5.670E+05	0.02599
6.557E+04	2.151E+05	0.01314	2.455E+05	8.054E+05	0.03400
6.566E+04	2.154E+05	0.01214	2.455E+05	8.055E+05	0.03025
6.566E+04	2.154E+05	0.01146	2.459E+05	8.067E+05	0.03118
6.570E+04	2.155E+05	0.01161	2.459E+05	8.069E+05	0.02937
6.570E+04	2.155E+05	0.01217	2.469E+05	8.100E+05	0.03124
6.583E+04	2.160E+05	0.01139	2.974E+05	9.758E+05	0.03704
6.585E+04	2.160E+05	0.01281	2.977E+05	9.766E+05	0.03253
6.615E+04	2.170E+05	0.01300	2.978E+05	9.771E+05	0.03453
8.584E+04	2.816E+05	0.01698	2.985E+05	9.794E+05	0.03121
8.589E+04	2.818E+05	0.01477	2.991E+05	9.814E+05	0.03411
8.605E+04	2.823E+05	0.01541	4.198E+05	1.377E+06	0.04245
8.613E+04	2.826E+05	0.01436	4.201E+05	1.378E+06	0.03768
8.655E+04	2.840E+05	0.01619	4.207E+05	1.380E+06	0.03920
1.214E+05	3.982E+05	0.02249	4.212E+05	1.382E+06	0.03597
1.214E+05	3.982E+05	0.01991	4.222E+05	1.385E+06	0.03906
1.216E+05	3.989E+05	0.02099	5.940E+05	1.949E+06	0.04222
1.218E+05	3.996E+05	0.01903	5.942E+05	1.949E+06	0.04751
1.223E+05	4.014E+05	0.02106	5.955E+05	1.954E+06	0.04383
1.486E+05	4.874E+05	0.02580	5.957E+05	1.954E+06	0.04105
1.487E+05	4.879E+05	0.02296	5.974E+05	1.960E+06	0.04360
1.490E+05	4.888E+05	0.02398	8.567E+05	2.811E+06	0.05314
1.491E+05	4.890E+05	0.02237	8.580E+05	2.815E+06	0.04672
1.498E+05	4.914E+05	0.02392	8.588E+05	2.818E+06	0.04954
1.718E+05	5.637E+05	0.02473	8.597E+05	2.821E+06	0.04505
1.720E+05	5.642E+05	0.02635	8.614E+05	2.826E+06	0.04876
1.722E+05	5.651E+05	0.02830			

Table C2. Effective porosity results for PIA-C-44378D Type I fabric.

$\hat{R}e$ (1/ft)	$\hat{R}e$ (1/m)	c_e	$\hat{R}e$ (1/ft)	$\hat{R}e$ (1/m)	c_e
6.571E+04	2.156E+05	0.0001611	1.733E+05	5.687E+05	0.0003211
6.576E+04	2.158E+05	0.0001868	1.744E+05	5.722E+05	0.0003176
6.576E+04	2.158E+05	0.0001581	2.460E+05	8.070E+05	0.0004962
6.581E+04	2.159E+05	0.0001931	2.461E+05	8.073E+05	0.0006098
6.590E+04	2.162E+05	0.0001733	2.474E+05	8.115E+05	0.0005370
6.608E+04	2.168E+05	0.0001545	2.478E+05	8.131E+05	0.0004730
6.614E+04	2.170E+05	0.0001526	2.493E+05	8.180E+05	0.0004568
6.636E+04	2.177E+05	0.0001718	2.980E+05	9.777E+05	0.0006182
6.643E+04	2.179E+05	0.0001526	2.983E+05	9.788E+05	0.0007383
6.643E+04	2.179E+05	0.0001484	2.997E+05	9.834E+05	0.0005589
8.607E+04	2.824E+05	0.0001912	3.003E+05	9.851E+05	0.0006537
8.612E+04	2.826E+05	0.0002257	3.023E+05	9.918E+05	0.0005572
8.625E+04	2.830E+05	0.0002071	4.209E+05	1.381E+06	0.0008478
8.681E+04	2.848E+05	0.0001844	4.212E+05	1.382E+06	0.0010196
8.700E+04	2.854E+05	0.0001774	4.241E+05	1.391E+06	0.0008910
1.217E+05	3.992E+05	0.0002627	4.245E+05	1.393E+06	0.0008026
1.218E+05	3.997E+05	0.0002979	4.270E+05	1.401E+06	0.0007869
1.220E+05	4.002E+05	0.0002663	5.957E+05	1.954E+06	0.0011637
1.229E+05	4.031E+05	0.0002487	5.960E+05	1.956E+06	0.0014435
1.231E+05	4.039E+05	0.0002306	6.007E+05	1.971E+06	0.0012593
1.490E+05	4.890E+05	0.0003001	6.016E+05	1.974E+06	0.0011284
1.491E+05	4.893E+05	0.0003685	6.031E+05	1.979E+06	0.0011077
1.496E+05	4.907E+05	0.0003257	8.593E+05	2.819E+06	0.0016214
1.504E+05	4.934E+05	0.0002852	8.600E+05	2.821E+06	0.0019795
1.509E+05	4.952E+05	0.0002756	8.660E+05	2.841E+06	0.0015584
1.721E+05	5.645E+05	0.0003522	8.666E+05	2.843E+06	0.0015847
1.723E+05	5.652E+05	0.0004170	8.674E+05	2.846E+06	0.0017806
1.729E+05	5.674E+05	0.0003727			

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13. SUPPLEMENTARY NOTES Corrected errors in the calculation of the effective porosity (and its consequences) in the example of section 4.3, “Effective Porosity.” Corrections did not change conclusions drawn from the example.

14. ABSTRACT

Two parachute fabrics, described by Parachute Industry Specifications PIA-C-7020D Type I and PIA-C-44378D Type I, were tested to obtain their permeabilities in air (i.e., flow through volume of air per area per time) over the range of differential pressures from 0.146 psf (7 Pa) to 25 psf (1197 Pa). Both fabrics met their specification permeabilities at the standard differential pressure of 0.5 inch of water (2.60 psf, 124 Pa). The permeability results were transformed into an effective porosity for use in calculations related to parachutes. Models were created that related the effective porosity to the unit Reynolds number for each of the fabrics. As an application example, these models were used to calculate the total porosities for two geometrically equivalent subscale Disk Gap Band (DGB) parachutes fabricated from each of the two fabrics, and tested at the same operating conditions in a wind tunnel. Using the calculated total porosities and the results of the wind tunnel tests, the drag coefficient of a geometrically equivalent full-scale DGB operating on Mars was estimated.

15. SUBJECT TERMS

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