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Permeability of a New Parachute Fabric – Measurements, Modeling, and Application

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Summary

In response to a NASA request, Heathcoat Fabrics Limited has woven a new parachute fabric (Custom Design 1 G-60315-1800-Q01). This fabric was tested to obtain its permeability in air (i.e., flow-through volume of air per area per time) over a range of differential pressures from 0.146 to 25 psf (7 to 1197 Pa). The fabric met its specification permeability of 60 to 100 $ft^3/ft^2/min$ (30.5 to 50.8 $cm^3/cm^2/s$) at the U.S. standard differential pressure of 0.5 inch of water (2.60 psf, 124 Pa). The permeability results were transformed into an effective porosity model for use in calculations related to the total porosity of parachutes. The tested fabric is being considered for use in parachutes for future missions to Mars. Calculations of drag coefficient were performed for two geometrically identical parachutes using either the new fabric or fabric woven to Parachute Industry Specification PIA-C-7020D Type I (Mars Science Laboratory Disk-Gap-Band parachute operating on Mars at a Mach number of 0.41). These calculations indicate essentially no difference in the drag coefficient between the two parachutes.

Symbols and Abbreviations

C_D	parachute drag coefficient (using S_0 as the reference area)
c_e	effective porosity
$c_{e,\text{Avg}}$	average effective porosity
D_P	parachute projected diameter
D_0	parachute nominal diameter
K_1, K_2	constants in the models for c_e
k	discharge coefficient
M	Mach number
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 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_{Max} - u_{Min}
V	airspeed
β	constant in Sutherland's formula for μ
Δp	differential pressure
λ_g	parachute geometric porosity
λ_T	parachute total porosity

μ	coefficient of viscosity
ρ	fluid density
DGB	Disk-Gap-Band (parachute type)
MSL	Mars Science Laboratory (mission)
NA	Not Available

1 Introduction

At NASA's request, Heathcoat Fabrics Limited in the United Kingdom is weaving a new fabric for use on parachutes for missions to Mars. This fabric is being woven to Heathcoat Fabrics Ltd. specification "Custom Design 1 G-60315-1800-Q01." This specification is presented in Appendix A. For the rest of this technical memorandum, this new fabric will be denoted as HFL G-60315.

Fabric permeability[1] can have an effect on the aerodynamic characteristics of parachutes. A set of fabric permeability tests was conducted on the HFL G-60315 fabric as part of its characterization. The present technical memorandum describes these tests and the data obtained from them. Using these data, the effective porosity of the fabric was calculated and mathematically modeled. This effective porosity model was then applied to the estimation of the drag coefficient of the Mars Science Laboratory (MSL) Disk-Gap-Band (DGB) parachute (refs. 1 and 2) by applying one of the mathematical aerodynamic models described in reference 3. Throughout this technical memorandum, comparisons are made between the HFL G-60315 fabric and the fabrics described in reference 4, namely, PIA-C-7020D Type I (ref. 5) and PIA-C-44378D Type I (ref. 6).

The tests and analyses presented here are almost identical to those described in reference 4. To make the present technical memorandum a stand-alone document, these descriptions of the tests and analyses are repeated herein, often verbatim.

2 Permeability Testing

2.1 Fabric

The HFL G-60315 fabric used in the permeability testing was woven by Heathcoat Fabrics in the United Kingdom as described by the specification in Appendix A. Key specification properties of this fabric are given in table 1.

Table 1. Key specification properties of HFL G-60315 fabric.

Fiber	Weave	Areal Weight	Permeability
Nylon	Plain weave, ripstop	1.76–1.94 oz/yd^2 (59.7–65.8 g/m^2)	60–100 ft^3/ft^2/min (30.5–50.8 cm^3/cm^2/s)

Permeability values when tested per ASTM International Test Method D737 (ref. 7) 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

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

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) 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 (up to 52 psf (2500 Pa)).

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

2.3 Test Samples

A piece of HFL G-60315 fabric of approximately 2.3 yd^2 (1.9 m^2) was provided to the testing laboratory. Five samples were selected from this piece of fabric. The location of the samples, and the numbering scheme used to identify them, are shown in figure 2. Each square in this figure was approximately 9 × 9 in (23 × 23 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.

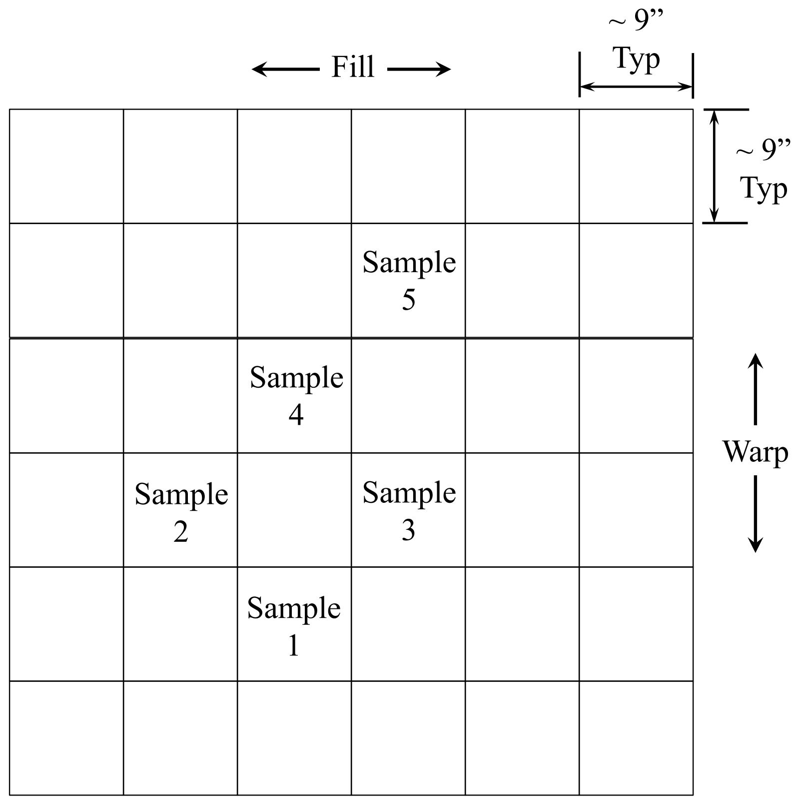


Figure 2. Position of samples on fabric.

2.4 Test Matrix

The test matrix is given in table 2. The test matrix is the same as that used in reference 4. Each sample was tested at ten values of differential pressure from 0.146 psf (7 Pa) to 25 psf (1197 Pa). 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. The test matrix in table 2 was repeated three times during three consecutive days. This repetition allows for the evaluation of precision uncertainty in the permeability results.

Table 2. Test matrix.

U.S. Customary Units

Sample	Differential Pressure, Δ*p* (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, Δ*p* (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 conditions. 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 being tested at the next value of the differential pressure. The entire test matrix was repeated three times over three consecutive days.

2.6 Data Acquisition

The following quantities were recorded during testing:

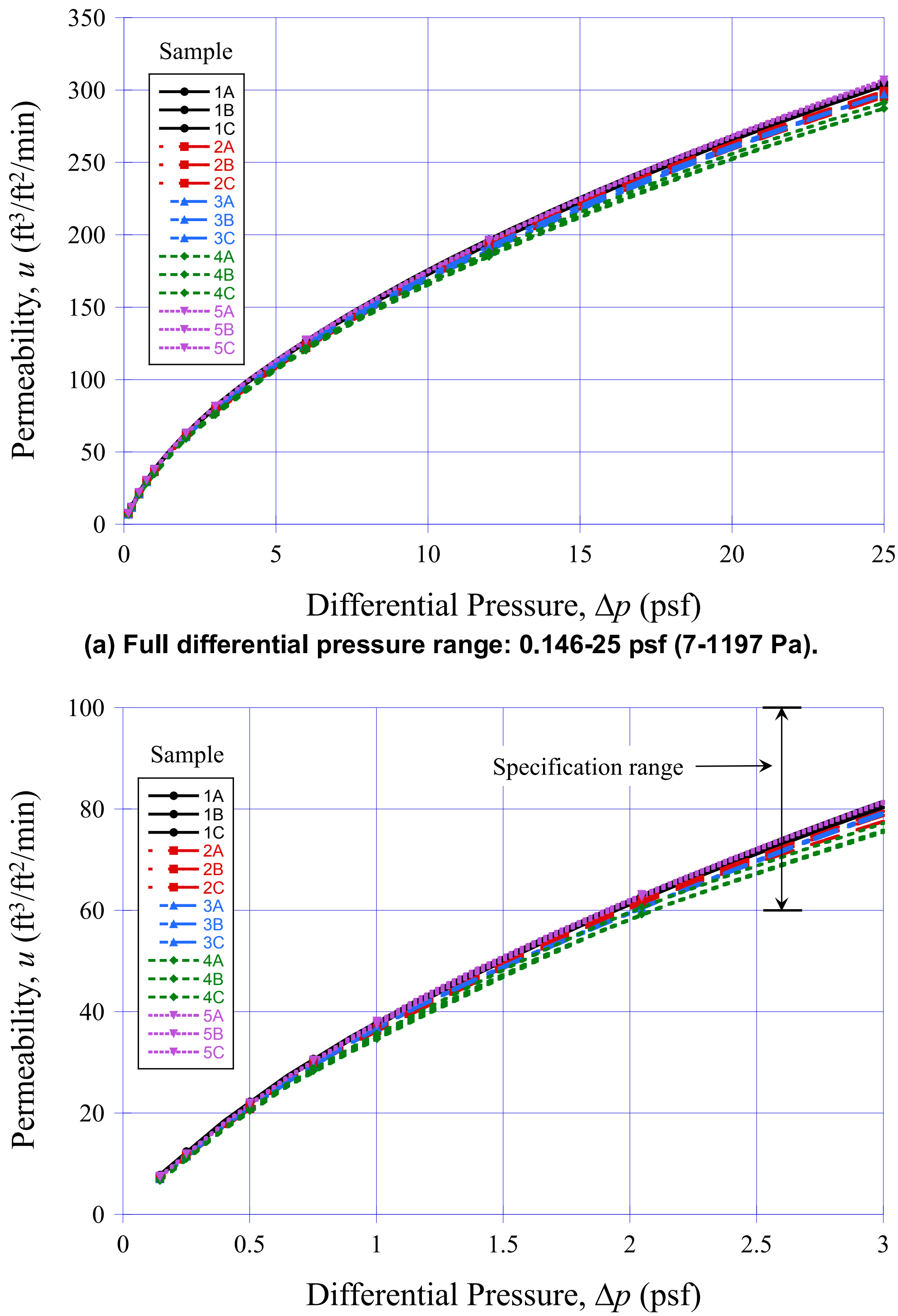
- Fabric type
- Sample number
- Date and time of test
- Atmospheric (upstream) pressure (in the laboratory), *p* (in Hg)
- Atmospheric temperature (in the laboratory), *T* (°F)
- Relative humidity (in the laboratory), *RH* (%)
- Differential pressure, Δ*p* (Pa)
- Permeability, *u* ($cm^3/cm^2/s$)

3 Permeability Test Results

The permeability results are shown graphically in figure 3 and in summary in table 3. Tests conducted on the same day have the same sample letter identifier (i.e., samples 1A, 2A, 3A, 4A, and 5A were tested on the same day). A complete set of permeability results is presented in a table in Appendix B.

Several observations can be made from these results:

1. The permeability increases with differential pressure over the range of differential pressures used in the test.
2. As shown in figure 3(b), the measured permeability values were within the specification range at the prescribed differential pressure of 0.5 inches of water (2.6 psf, 124 Pa). (Note: The test protocol used was not exactly the same as that described in reference 7.)
3. The day-to-day variations in the results for a given sample are shown in figure 3 by using the same line type and symbol (e.g., 4A, 4B, and 4C for sample 4 on days A, B, and C). The day-to-day variation is relatively small for a given sample.
4. The variation in the permeability results at a given differential pressure in table 3 is quantified in the last column. The fabric permeability range divided by the average value, u_R/u_{Avg}, was in the range from 0.06 to 0.12, except for the lowest differential pressure, which was 0.16. For the fabrics investigated in reference 4 the values of u_R/u_{Avg} were 0.15 to 0.18 for the PIA-C-7020D Type I fabric and 0.25 to 0.30 for the PIA-C-44378D Type I fabric over the same range of differential pressures as that used in the present technical memorandum.



(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.

Table 3. Summary of permeability results.

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	7.28	6.67	7.83	1.16	7.0	3.70	3.39	3.98	0.59	0.16
0.251	11.75	11.02	12.46	1.44	12.0	5.97	5.60	6.33	0.73	0.12
0.501	21.44	20.47	22.24	1.77	24.0	10.89	10.40	11.30	0.90	0.08
0.752	29.76	28.35	30.71	2.36	36.0	15.12	14.40	15.60	1.20	0.08
1.003	36.80	34.65	38.19	3.54	48.0	18.69	17.60	19.40	1.80	0.10
2.047	61.52	59.25	63.19	3.94	98.0	31.25	30.10	32.10	2.00	0.06
3.008	79.42	75.59	81.69	6.10	144.0	40.35	38.40	41.50	3.10	0.08
5.994	124.30	120.28	127.36	7.09	287.0	63.14	61.10	64.70	3.60	0.06
12.009	191.97	185.04	196.85	11.81	575.0	97.52	94.00	100.00	6.00	0.06
25.000	298.82	287.40	307.09	19.69	1197.0	151.80	146.00	156.00	10.00	0.07

Note: Data for all samples at a specific differential pressure were used to determine the average, minimum, maximum, and range of permeability.

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 8 and in unpublished lecture notes by Lingard in reference 9.

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 assumed 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 from equations (1)–(3) using the following additional equations and constants: the equation of state and the gas constant for air, R, (ref. 10)

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

$$R = 1716.56\ \frac{\text{ft•lb}}{\text{slug•°R}} \quad \left(287.053\ \frac{\text{N•m}}{\text{kg•K}}\right) \tag{4b}$$

and Sutherland's formula for μ, and its constants β and S for air (ref. 10)

[2] See reference 11, Section III "The Concept of Effective Porosity," pp. 10–12.

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

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

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

The value of μ was calculated in SI units (N•s/m^2) using the equation and constants from reference 10 and then converted to U.S. Customary Units (lb•s/ft^2).

The permeability results were processed to yield c_e versus $\hat{Re}$. These effective porosity results are shown by symbols (dots) in figure 4 and in summary (averaging points at the same value of Δp) in table 4. A complete set of effective porosity results are given in tables in Appendix C.

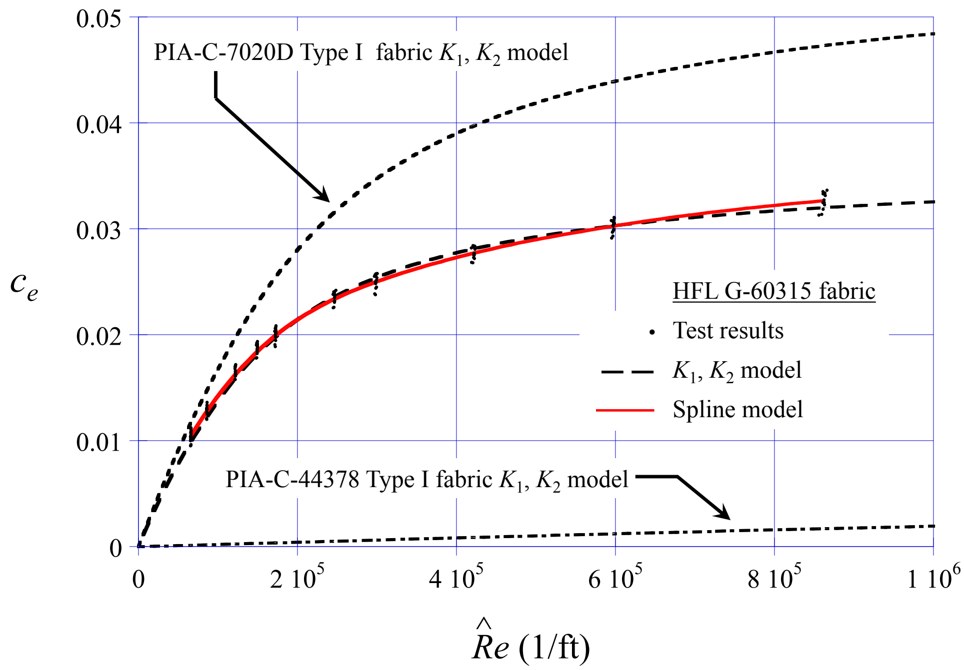


Figure 4. Effective porosity results and models.

Table 4. Effective porosity results and spline model.

$\hat{R}e_{\text{Avg}}$		$c_{e,\text{Avg}}$ Avg. Test Results	c_e Spline Model
(1/ft)	(1/m)		
6.589E+04	2.162E+05	0.01041	0.01049
8.620E+04	2.828E+05	0.01283	0.01280
1.219E+05	3.999E+05	0.01655	0.01647
1.493E+05	4.898E+05	0.01875	0.01868
1.725E+05	5.658E+05	0.02008	0.02015
2.465E+05	8.087E+05	0.02350	0.02349
2.987E+05	9.799E+05	0.02502	0.02504
4.216E+05	1.383E+06	0.02774	0.02774
5.973E+05	1.960E+06	0.03028	0.03028
8.618E+05	2.828E+06	0.03266	0.03266

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 8, the following equation is proposed to model the relationship between c_e and $\hat{R}e$,

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

where K_1 and K_2 are constants dependent only on the specific fabric. A nonlinear least-squares fit of the porosity data presented in Appendix B was performed using equation (6). The values of K_1 and K_2 obtained from this fit are given in table 5. The curve created using this fit is shown in figure 4 as a long-dashed line labeled "HFL G-60315 fabric K_1, K_2 model" (Note: The fit is shown extrapolated for values of $\hat{R}e$ beyond the available porosity test data). As can be seen from figure 4, equation (6) with appropriate values of K_1 and K_2 provide good fits to the porosity results.

Table 5. Fitted values of K_1 and K_2.

K_1	K_2	
(dimensionless)	(1/ft)	(1/m)
3.80678861E+02	2.96130992E+06	9.71558374E+06

An additional model for the HFL G-60315 fabric is shown in figure 4 and presented numerically in table 4. The values of $c_{e,\text{Avg}}$ and $\hat{R}e_{\text{Avg}}$ in table 4 were used to create a spline model. This model attempted to fit the porosity results with a smooth curve that was not required to go through each point $(c_{e,\text{Avg}}, \hat{R}e_{\text{Avg}})$. The spline model is shown as a solid red line in figure 4. This spline model provides an alternative to the "HFL G-60315 fabric K_1, K_2 model" defined by equation (6) and may be a better model of the data in some intervals. Note, however, that the spline model is not suitable for extrapolation to values of $\hat{R}e$ beyond those used to create it.

For comparison, the effective porosity of PIA-C-7020D Type I and PIA-C-44378D Type I fabrics as calculated from their respective "K_1, K_2" models are also shown in figure 4 as a short-dashed line and a dash-dot line, respectively. The values of K_1 and K_2 used for calculating the effective porosity of these fabrics are those reported in reference 4. Comparing the effective porosity of HFL G-60315 fabric to the two fabrics mentioned above, it is seen that the PIA-C-7020D Type I fabric has a higher effective porosity, whereas the PIA-C-44378D Type I fabric has a lower effective porosity.

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.[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 permeability. To estimate c_e, an appropriate value of $\hat{R}e$ 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

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

In equation (8), it is assumed that the flight condition is known; therefore, ρ and μ are known. Thus, what remains to be done to calculate $\hat{R}e$ is to determine Δp. Following the approach presented in reference 8, Δp is calculated from the equation

$$\Delta p = \frac{qC_D S_0}{S_P} \tag{9}$$

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.[4] 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. Combining equations (8) and (9) yields

[3] In reference 9 it is suggested that k be assigned a value between 0.6 and 0.7. In reference 12 values of k between 0.928 and 0.973 were calculated by computational fluid dynamics.

[4] This method for the calculation of Δp is denoted "Method 1" in reference 4. The alternate "Method 2" of reference 4 is not used in the present technical memorandum.

$$\hat{Re} = \frac{\rho V}{\mu} \frac{D_0}{D_P} \sqrt{C_D} \tag{10}$$

where V is the airspeed, D_0 is the parachute's nominal diameter, and D_P is the parachute's projected diameter.

An example set of calculations was performed for the representative set of Mars flight conditions shown in table 6, the DGB parachute described in table 7, and using the appropriate drag coefficient model presented in reference 3. In addition, it was assumed that k = 0.7. These calculations were performed for parachutes fabricated from HFL G-60315, PIA-C-7020D Type I, and PIA-C-44378D Type I fabrics. The results of these calculations are shown in table 8. Several observations can be made from the results in table 8 for the Mars flight condition specified in table 6:

1. The values of $\hat{Re}$ are very low; of the order of 2.4×10^4 ft^{-1} (7.7×10^4 m^{-1}).
2. As can be seen from figure 4 and table 8, at the low values of $\hat{Re}$, the values of c_e are commensurably small.
3. Because the values of c_e are small, the magnitudes of the fabric permeability terms, $(1 - \lambda_g)c_e$, are a small portion of the total porosity, λ_T (see equation (7) and table 8).
4. A consequence of the above is that the difference in the values of C_D at the example Mars operating flight condition is negligibly small between parachutes fabricated from the HFL G-60315 and PIA-C-7020D Type I fabrics (0.6154 versus 0.6146). For the same reasons, the value of C_D for a parachute from the low-permeability PIA-C-44378D Type I fabric is only about 1 percent greater than parachutes fabricated from either HFL G-60315 or PIA-C-7020D Type I fabrics.

Note that, as described in references 1 and 2, the MSL parachute was mostly fabricated from fabrics woven to an earlier version of the same specification (i.e., versions -7020B and -7020C as compared to PIA-C-7020D Type I, reference 5). Thus, the drag coefficient result presented in table 8 for PIA-C-7020D Type I is a good representation of the value for MSL.

Table 6. Conditions experienced by MSL during descent on Mars at a Mach number of 0.41, as obtained from flight reconstruction (ref. 2).

Quantity	Units	Value
q	psf	0.8217
	Pa	39.34
V	ft/s	317.8
	m/s	96.87
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 7. Additional data on the MSL parachute.

Quantity	Value	Comment
λ_g	0.1280	Actual value for the MSL parachute (refs. 1 and 2).
S_0 / S_P	1.856	Assumed to be the same as that of the subscale DGB parachutes described in reference 13.
D_0 / D_P	1.362	

Table 8. Example calculations for the MSL parachute operating on Mars.

Quantity	Units	Parachute Fabric		
		HFL G-60315	PIA-C-7020D Type I	PIA-C-44378D Type I
$\hat{Re}$	1/ft	2.358E+04	2.356E+04	2.369E+04
	1/m	7.737E+04	7.731E+04	7.775E+04
c_e	-	0.003934	0.004451	0.000050
$k\lambda_g$	-	0.08960	0.08960	0.08960
$(1-\lambda_g)c_e$	-	0.00343	0.00388	0.00004
λ_T	-	0.09303	0.09348	0.08964
C_D	-	0.6154	0.6146	0.6216

Notes:

1. For the PIA-C-7020D Type I fabric, the values of K_1 and K_2 used in the calculation of c_e were K_1 = 1.5881679E+02 and K_2 = 2.63019691E+06 ft^{-1} (8.62925494E+06 m^{-1}) (ref. 4).
2. For the PIA-C-44378D Type I fabric, the values of K_1 and K_2 used in the calculation of c_e were K_1 = 1.1303031E+04 and K_2 = 2.37148232E+08 ft^{-1} (7.78045379E+08 m^{-1}) (ref. 4).
3. The value of k used in the calculations was 0.7. This value is consistent with that used in reference 3.
4. The value of C_D was calculated using the appropriate model for the MSL parachute from reference 3: $C_D = 0.7602148 - 1.811319\lambda_T + 0.0578995M$, where M is the Mach number.
5. The value of C_D appears as an input in the calculation of $\hat{Re}$ (see equation (10)), and as the result of the model $C_D(\lambda_T, M)$ as described in Note 4 above. Thus, the calculation of C_D is iterative.

5 Concluding Remarks

Permeability data for the HFL G-60315 fabric have been acquired and analyzed. Models for the effective porosity of the HFL G-60315 fabric have been created. Application of one of these models to the MSL parachute indicates that the subsonic drag coefficient of a parachute using HFL G-60315 fabric and operating on Mars should be nearly identical to that of the MSL parachute.

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Appendix A. Fabric Specification

Custom Design – G-60315-1800-Q01 According to Statement of Work 1559224
Performance Specification

TEXTILE, PARACHUTE, NYLON RIPSTOP

1 SCOPE

This specification covers ripstop weave, nylon parachute fabric

2 APPLICABLE DOCUMENTS

ASTM D 3374
ASTM D 3376
ASTM D 3375
ASTM D 1777
ASTM D 5035
ASTM D 2261
ASTM D 737
PIA-C-7020

3 REQUIREMENTS

3.1 Yarn: The yarn used in the manufacture of this fabric shall be continuous multifilament, bright, high tenacity, UV and heat resistant polyamide 66 (100%).

3.1.1 Yarn Twist: Proprietary information - Heathcoat Fabrics Limited

3.1.2 Heat & UV Resistance: Yarn shall use a suitable protection system. It shall not lose more than 5% of its original strength after 60mins at 180°C.

3.1.3 Suitability: A yarn from Heathcoat Advanced Yarns with characteristics as TABLE 1 has been designed and found to be suitable in meeting the requirements of this specification.

TABLE 1.		
Characteristic:	**Units**	**Measurement**
Linear Density	Denier	Proprietary information - Heathcoat Fabrics Limited
Tenacity	g/denier	Proprietary information - Heathcoat Fabrics Limited

3.2 Weave: The weave shall be plain weave with a ripstop pattern – further details are proprietary information – Heathcoat Fabrics Limited.

3.3 Physical Properties: The physical properties of the fabric shall conform to TABLE 2.

3.4 Physical Characteristics: Finished fabric shall not lose more than 25% of its original strength when exposed to heat and light in accordance with the test specified in PIA-C-7020E (Light and Heat Resistance).

3.5 Finish: The fabric shall be scoured to remove sizing and other contaminants, dyed as required according to customer order, heat-set and silicone emulsion applied and trimmed to width.

3.5.1 Scouring: Shall not cause fixation of the size into the fabric or result in permanent setting of the fabric.

3.5.2 Dyeing: If colour is required, fabric shall be piece dyed to achieve visual match to standard according to customer requirements.

3.5.3 Heat Set & Silicone Emulsion: Shall be evenly distributed throughout the fabric.

3.5.4 **Trim to Width:** Fabric shall be trimmed to produce an ultrasonically sealed edge with pinholes from processing removed.

3.6 **Inspection:** All fabric shall be visually inspected according to the standard outlined in PIA-C-7020.

3.7 **Testing:** Fabric shall be sampled and tested to confirm it meets the requirements of this specification and applicable customer order.

3.7.1 **Sampling:** Fabric shall be sampled at least every 650lin.yards of finisher's roll.

3.7.2 **Testing:** Finished fabric shall be tested according to the methods identified in this specification as per TABLE 2.

3.7.3 **Reporting:** Data shall be reported to confirm fabric performs according to TABLE 2.

3.7.4 **Compliance:** All other aspects of the specification shall be met through internal quality control and testing where appropriate. Type testing can be used to confirm compliance.

TABLE 2.

Characteristic:	**Test Method**	**Units**	**Requirement**
Width	ASTM D 3374	Inches	72-74
Weight	ASTM D 3776	ozs/yd^2	1.76-1.94
Ends	ASTM D 3775	/inch	Proprietary information - HFL
Picks (Fill)	ASTM D 3775	/inch	Proprietary information - HFL
Gauge	ASTM D 1777	inches	0.003-0.007
Warp Tensile	ASTM D 5035 (Strip)[1]	lbs/inch	>98
Warp Ext at Break	ASTM D 5035 (Strip)[1]	%	>32
Weft (Fill) Tensile	ASTM D 5035 (Strip)[1]	lbs/inch	>98
Weft Ext at Break	ASTM D 5035 (Strip)[1]	%	>32
Warp Tear	ASTM D 2261	lbs	>11
Weft (Fill) Tear	ASTM D 2261	lbs	>10
Air Permeability	ASTM D 737	cfm	60-100

[1]The use of pneumatic clamps is recommended to avoid slippage of fabric from clamping jaws. Any slippage can cause unexpected results.

4 ADDITIONAL INFORMATION:

4.1 **Source:** Specification and fabric developed by Heathcoat Fabrics Limited, England for Jet Propulsion Laboratory, California Institute of Technology.

4.2 **Heathcoat Fabrics Limited:** Registered Office: Westexe, Tiverton, Devon EX16 5LL England
Telephone: **+44 (0)1884 254949** Email: **info@heathcoat.co.uk** Registered in England No. 450787

Appendix B. Permeability Test Results

Table B1. Permeability test results in chronological order.

Sample	Date	Time (PDT)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
1A	4/4/17	5:47	27.64	1955	93600	70.1	529.8	294.3	21.2	0.146	7.0	7.72	3.92
1A	4/4/17	5:52	27.65	1956	93634	70.2	529.9	294.4	21.2	0.251	12.0	12.26	6.23
1A	4/4/17	5:56	27.65	1956	93634	70.3	530.0	294.4	21.2	0.501	24.0	22.24	11.30
1A	4/4/17	6:01	27.65	1956	93634	70.0	529.7	294.3	21.2	0.752	36.0	30.31	15.40
1A	4/4/17	6:05	27.65	1956	93634	69.8	529.5	294.2	21.2	1.003	48.0	37.40	19.00
1A	4/4/17	6:09	27.66	1956	93668	69.7	529.4	294.1	21.8	2.047	98.0	62.20	31.60
1A	4/4/17	6:15	27.66	1956	93668	69.6	529.3	294.0	22.4	3.008	144.0	80.51	40.90
1A	4/4/17	6:20	27.66	1956	93668	69.6	529.3	294.0	22.4	5.994	287.0	125.79	63.90
1A	4/4/17	6:25	27.66	1956	93668	69.7	529.4	294.1	22.4	12.009	575.0	193.50	98.30
1A	4/4/17	6:29	27.66	1956	93668	69.8	529.5	294.2	22.4	25.000	1197.0	303.15	154.00
1A	4/4/17	6:33	27.66	1956	93668	69.8	529.5	294.2	22.4	0.146	7.0	7.66	3.89
2A	4/4/17	6:35	27.67	1957	93701	70.0	529.7	294.3	22.4	0.146	7.0	7.22	3.67
2A	4/4/17	6:40	27.67	1957	93701	70.1	529.8	294.3	22.4	1.003	48.0	36.22	18.40
2A	4/4/17	6:44	27.67	1957	93701	70.1	529.8	294.3	22.4	3.008	144.0	77.76	39.50
2A	4/4/17	6:48	27.68	1958	93735	70.2	529.9	294.4	22.2	0.251	12.0	11.59	5.89
2A	4/4/17	6:53	27.68	1958	93735	70.3	530.0	294.4	22.4	0.501	24.0	21.06	10.70
2A	4/4/17	6:58	27.68	1958	93735	70.4	530.1	294.5	21.8	5.994	287.0	121.85	61.90
2A	4/4/17	7:02	27.68	1958	93735	70.4	530.1	294.5	21.2	25.000	1197.0	295.28	150.00
2A	4/4/17	7:06	27.68	1958	93735	70.4	530.1	294.5	21.2	12.009	575.0	189.96	96.50
2A	4/4/17	7:11	27.69	1958	93769	70.5	530.2	294.5	21.2	0.752	36.0	29.92	15.20
2A	4/4/17	7:15	27.69	1958	93769	70.7	530.4	294.7	21.2	2.047	98.0	61.61	31.30
2A	4/4/17	7:19	27.69	1958	93769	70.8	530.5	294.7	21.2	0.146	7.0	7.24	3.68

Table B1. Continued.

Sample	Date	Time (PDT)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
3A	4/4/17	7:20	27.69	1958	93769	70.8	530.5	294.7	21.2	0.146	7.0	7.13	3.62
3A	4/4/17	7:24	27.69	1958	93769	70.9	530.6	294.8	21.2	0.251	12.0	11.65	5.92
3A	4/4/17	7:28	27.70	1959	93803	71.0	530.7	294.8	21.2	2.047	98.0	60.43	30.70
3A	4/4/17	7:33	27.70	1959	93803	71.2	530.9	294.9	21.2	12.009	575.0	192.13	97.60
3A	4/4/17	7:37	27.70	1959	93803	71.3	531.0	295.0	21.2	5.994	287.0	NA	NA
3A	4/4/17	7:42	27.70	1959	93803	71.4	531.1	295.0	21.2	0.752	36.0	29.53	15.00
3A	4/4/17	7:46	27.71	1960	93837	71.6	531.3	295.2	21.1	25.000	1197.0	297.24	151.00
3A	4/4/17	7:51	27.70	1959	93803	71.7	531.4	295.2	20.6	1.003	48.0	36.81	18.70
3A	4/4/17	7:55	27.71	1960	93837	71.8	531.5	295.3	20.6	0.501	24.0	21.26	10.80
3A	4/4/17	7:59	27.71	1960	93837	72.0	531.7	295.4	21.1	3.008	144.0	79.33	40.30
3A	4/4/17	8:04	27.71	1960	93837	72.1	531.8	295.4	21.3	0.146	7.0	7.05	3.58
4A	4/4/17	8:04	27.71	1960	93837	72.1	531.8	295.4	21.3	0.146	7.0	6.69	3.40
4A	4/4/17	8:09	27.71	1960	93837	72.1	531.8	295.4	21.3	3.008	144.0	75.59	38.40
4A	4/4/17	8:13	27.71	1960	93837	72.2	531.9	295.5	21.3	1.003	48.0	34.65	17.60
4A	4/4/17	8:18	27.71	1960	93837	72.3	532.0	295.5	21.3	25.000	1197.0	287.40	146.00
4A	4/4/17	8:22	27.71	1960	93837	72.3	532.0	295.5	21.3	2.047	98.0	59.25	30.10
4A	4/4/17	8:27	27.71	1960	93837	72.3	532.0	295.5	21.3	0.251	12.0	11.02	5.60
4A	4/4/17	8:31	27.71	1960	93837	72.4	532.1	295.6	21.3	5.994	287.0	120.28	61.10
4A	4/4/17	8:36	27.71	1960	93837	72.4	532.1	295.6	21.3	0.752	36.0	28.35	14.40
4A	4/4/17	8:40	27.71	1960	93837	72.6	532.3	295.7	21.3	0.501	24.0	20.47	10.40
4A	4/4/17	8:44	27.71	1960	93837	72.6	532.3	295.7	21.3	12.009	575.0	185.04	94.00
4A	4/4/17	8:48	27.71	1960	93837	72.6	532.3	295.7	21.3	0.146	7.0	6.67	3.39

Table B1. Continued.

Sample	Date	Time (PDT)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
5A	4/4/17	8:50	27.72	1961	93871	72.8	532.5	295.8	21.3	0.146	7.0	7.30	3.71
5A	4/4/17	8:54	27.72	1961	93871	72.8	532.5	295.8	21.3	0.251	12.0	11.93	6.06
5A	4/4/17	8:59	27.71	1960	93837	73.1	532.8	296.0	21.3	0.501	24.0	22.05	11.20
5A	4/4/17	9:03	27.72	1961	93871	71.3	531.0	295.0	21.2	0.752	36.0	30.31	15.40
5A	4/4/17	9:08	27.72	1961	93871	70.3	530.0	294.4	20.4	1.003	48.0	38.19	19.40
5A	4/4/17	9:12	27.72	1961	93871	68.0	527.7	293.2	26.5	2.047	98.0	63.19	32.10
5A	4/4/17	9:16	27.72	1961	93871	69.4	529.1	293.9	23.9	3.008	144.0	81.69	41.50
5A	4/4/17	9:21	27.73	1961	93905	70.3	530.0	294.4	23.0	5.994	287.0	126.97	64.50
5A	4/4/17	9:25	27.73	1961	93905	70.8	530.5	294.7	22.4	12.009	575.0	195.28	99.20
5A	4/4/17	9:30	27.73	1961	93905	71.3	531.0	295.0	22.4	25.000	1197.0	305.12	155.00
5A	4/4/17	9:34	27.72	1961	93871	71.8	531.5	295.3	21.8	0.146	7.0	7.54	3.83
1B	4/5/17	6:20	27.76	1963	94006	70.5	530.2	294.5	16.6	0.146	7.0	7.83	3.98
1B	4/5/17	6:24	27.76	1963	94006	70.7	530.4	294.7	16.6	0.251	12.0	12.46	6.33
1B	4/5/17	6:29	27.77	1964	94040	70.8	530.5	294.7	16.6	0.501	24.0	22.24	11.30
1B	4/5/17	6:33	27.76	1963	94006	71.0	530.7	294.8	16.6	0.752	36.0	30.71	15.60
1B	4/5/17	6:37	27.77	1964	94040	71.1	530.8	294.9	16.6	1.003	48.0	37.99	19.30
1B	4/5/17	6:42	27.77	1964	94040	71.3	531.0	295.0	16.6	2.047	98.0	62.99	32.00
1B	4/5/17	6:46	27.77	1964	94040	71.5	531.2	295.1	16.6	3.008	144.0	81.69	41.50
1B	4/5/17	6:51	27.77	1964	94040	71.4	531.1	295.0	17.0	5.994	287.0	126.97	64.50
1B	4/5/17	6:55	27.77	1964	94040	70.8	530.5	294.7	17.6	12.009	575.0	196.85	100.00
1B	4/5/17	6:59	27.77	1964	94040	70.8	530.5	294.7	17.5	25.000	1197.0	305.12	155.00
1B	4/5/17	7:03	27.78	1965	94074	70.9	530.6	294.8	17.2	0.146	7.0	7.80	3.96

Table B1. Continued.

Sample	Date	Time (PDT)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
2B	4/5/17	7:05	27.78	1965	94074	71.0	530.7	294.8	17.2	0.146	7.0	7.38	3.75
2B	4/5/17	7:09	27.78	1965	94074	71.0	530.7	294.8	17.0	1.003	48.0	36.81	18.70
2B	4/5/17	7:13	27.78	1965	94074	71.1	530.8	294.9	17.0	3.008	144.0	79.72	40.50
2B	4/5/17	7:17	27.77	1964	94040	71.3	531.0	295.0	16.6	0.251	12.0	11.89	6.04
2B	4/5/17	7:22	27.78	1965	94074	71.3	531.0	295.0	16.6	0.501	24.0	20.87	10.60
2B	4/5/17	7:26	27.78	1965	94074	71.3	531.0	295.0	16.6	5.994	287.0	124.02	63.00
2B	4/5/17	7:30	27.78	1965	94074	71.4	531.1	295.0	16.6	25.000	1197.0	299.21	152.00
2B	4/5/17	7:35	27.78	1965	94074	71.4	531.1	295.0	16.6	12.009	575.0	193.90	98.50
2B	4/5/17	7:39	27.78	1965	94074	71.4	531.1	295.0	16.6	0.752	36.0	30.12	15.30
2B	4/5/17	7:44	27.78	1965	94074	71.4	531.1	295.0	17.0	2.047	98.0	62.01	31.50
2B	4/5/17	7:48	27.79	1965	94108	71.3	531.0	295.0	16.8	0.146	7.0	7.24	3.68
3B	4/5/17	7:49	27.78	1965	94074	71.3	531.0	295.0	17.2	0.146	7.0	7.17	3.64
3B	4/5/17	7:53	27.79	1965	94108	71.3	531.0	295.0	17.0	0.251	12.0	11.48	5.83
3B	4/5/17	7:58	27.79	1965	94108	71.3	531.0	295.0	17.0	2.047	98.0	60.63	30.80
3B	4/5/17	8:02	27.79	1965	94108	71.3	531.0	295.0	17.3	12.009	575.0	189.37	96.20
3B	4/5/17	8:06	27.79	1965	94108	71.8	531.5	295.3	17.8	5.994	287.0	123.82	62.90
3B	4/5/17	8:10	27.79	1965	94108	71.8	531.5	295.3	17.8	0.752	36.0	29.53	15.00
3B	4/5/17	8:14	27.79	1965	94108	71.6	531.3	295.2	17.6	25.000	1197.0	297.24	151.00
3B	4/5/17	8:19	27.79	1965	94108	71.4	531.1	295.0	17.8	1.003	48.0	37.01	18.80
3B	4/5/17	8:23	27.79	1965	94108	71.6	531.3	295.2	17.8	0.501	24.0	21.46	10.90
3B	4/5/17	8:28	27.79	1965	94108	71.7	531.4	295.2	17.8	3.008	144.0	79.53	40.40
3B	4/5/17	8:32	27.79	1965	94108	71.8	531.5	295.3	17.8	0.146	7.0	7.26	3.69

Table B1. Continued.

Sample	Date	Time (PDT)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
4B	4/5/17	8:33	27.79	1965	94108	71.9	531.6	295.3	17.8	0.146	7.0	7.09	3.60
4B	4/5/17	8:37	27.79	1965	94108	71.9	531.6	295.3	17.8	3.008	144.0	77.36	39.30
4B	4/5/17	8:41	27.79	1965	94108	72.0	531.7	295.4	17.8	1.003	48.0	35.63	18.10
4B	4/5/17	8:45	27.80	1966	94142	72.1	531.8	295.4	17.8	25.000	1197.0	291.34	148.00
4B	4/5/17	8:50	27.80	1966	94142	72.1	531.8	295.4	17.8	2.047	98.0	60.63	30.80
4B	4/5/17	8:54	27.80	1966	94142	72.3	532.0	295.5	17.8	0.251	12.0	11.52	5.85
4B	4/5/17	8:58	27.80	1966	94142	72.3	532.0	295.5	17.8	5.994	287.0	122.24	62.10
4B	4/5/17	9:03	27.80	1966	94142	72.6	532.3	295.7	17.8	0.752	36.0	28.94	14.70
4B	4/5/17	9:07	27.80	1966	94142	72.6	532.3	295.7	17.2	0.501	24.0	20.87	10.60
4B	4/5/17	9:12	27.80	1966	94142	72.6	532.3	295.7	16.9	12.009	575.0	188.19	95.60
4B	4/5/17	9:17	27.80	1966	94142	72.6	532.3	295.7	16.6	0.146	7.0	7.03	3.57
5B	4/5/17	9:18	27.80	1966	94142	72.7	532.4	295.8	17.5	0.146	7.0	7.48	3.80
5B	4/5/17	9:22	27.80	1966	94142	72.8	532.5	295.8	17.2	0.251	12.0	12.01	6.10
5B	4/5/17	9:26	27.79	1965	94108	72.8	532.5	295.8	16.7	0.501	24.0	22.05	11.20
5B	4/5/17	9:30	27.79	1965	94108	72.9	532.6	295.9	16.7	0.752	36.0	30.51	15.50
5B	4/5/17	9:35	27.79	1965	94108	73.1	532.8	296.0	16.7	1.003	48.0	37.80	19.20
5B	4/5/17	9:39	27.79	1965	94108	73.3	533.0	296.1	16.7	2.047	98.0	62.99	32.00
5B	4/5/17	9:43	27.79	1965	94108	73.4	533.1	296.2	16.7	3.008	144.0	81.50	41.40
5B	4/5/17	9:48	27.79	1965	94108	72.8	532.5	295.8	16.7	5.994	287.0	127.36	64.70
5B	4/5/17	9:52	27.79	1965	94108	70.8	530.5	294.7	17.7	12.009	575.0	196.46	99.80
5B	4/5/17	9:56	27.79	1965	94108	69.7	529.4	294.1	18.6	25.000	1197.0	307.09	156.00
5B	4/5/17	10:00	27.79	1965	94108	69.6	529.3	294.0	19.7	0.146	7.0	7.62	3.87

Table B1. Continued.

Sample	Date	Time (PDT)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δp		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
1C	4/6/17	5:31	27.63	1954	93566	70.5	530.2	294.5	20.0	0.146	7.0	7.80	3.96
1C	4/6/17	5:36	27.63	1954	93566	70.5	530.2	294.5	20.0	0.251	12.0	12.22	6.21
1C	4/6/17	5:40	27.63	1954	93566	70.5	530.2	294.5	20.0	0.501	24.0	22.05	11.20
1C	4/6/17	5:45	27.63	1954	93566	70.7	530.4	294.7	20.0	0.752	36.0	30.51	15.50
1C	4/6/17	5:49	27.64	1955	93600	70.8	530.5	294.7	20.0	1.003	48.0	37.80	19.20
1C	4/6/17	5:53	27.63	1954	93566	70.8	530.5	294.7	20.0	2.047	98.0	62.80	31.90
1C	4/6/17	5:57	27.63	1954	93566	70.8	530.5	294.7	21.5	3.008	144.0	81.30	41.30
1C	4/6/17	6:01	27.64	1955	93600	70.8	530.5	294.7	20.0	5.994	287.0	126.77	64.40
1C	4/6/17	6:05	27.63	1954	93566	70.9	530.6	294.8	20.0	12.009	575.0	194.88	99.00
1C	4/6/17	6:10	27.63	1954	93566	70.9	530.6	294.8	20.0	25.000	1197.0	305.12	155.00
1C	4/6/17	6:14	27.63	1954	93566	71.0	530.7	294.8	20.0	0.146	7.0	7.60	3.86
2C	4/6/17	6:15	27.63	1954	93566	71.0	530.7	294.8	20.0	0.146	7.0	7.15	3.63
2C	4/6/17	6:19	27.64	1955	93600	71.0	530.7	294.8	21.1	1.003	48.0	36.42	18.50
2C	4/6/17	6:23	27.63	1954	93566	71.1	530.8	294.9	21.1	3.008	144.0	78.94	40.10
2C	4/6/17	6:28	27.64	1955	93600	71.1	530.8	294.9	21.2	0.251	12.0	11.63	5.91
2C	4/6/17	6:32	27.64	1955	93600	70.8	530.5	294.7	21.3	0.501	24.0	21.46	10.90
2C	4/6/17	6:36	27.64	1955	93600	70.4	530.1	294.5	22.4	5.994	287.0	123.43	62.70
2C	4/6/17	6:40	27.64	1955	93600	70.3	530.0	294.4	22.4	25.000	1197.0	297.24	151.00
2C	4/6/17	6:44	27.64	1955	93600	70.4	530.1	294.5	22.4	12.009	575.0	192.91	98.00
2C	4/6/17	6:49	27.64	1955	93600	70.5	530.2	294.5	22.4	0.752	36.0	29.72	15.10
2C	4/6/17	6:53	27.64	1955	93600	70.5	530.2	294.5	22.4	2.047	98.0	61.61	31.30
2C	4/6/17	6:57	27.64	1955	93600	70.6	530.3	294.6	22.4	0.146	7.0	7.19	3.65

Table B1. Continued.

Sample	Date	Time (PDT)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δ*p*		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
3C	4/6/17	6:58	27.65	1956	93634	70.7	530.4	294.7	22.4	0.146	7.0	7.07	3.59
3C	4/6/17	7:03	27.65	1956	93634	70.7	530.4	294.7	22.4	0.251	12.0	11.59	5.89
3C	4/6/17	7:07	27.65	1956	93634	70.7	530.4	294.7	22.4	2.047	98.0	60.63	30.80
3C	4/6/17	7:11	27.64	1955	93600	70.8	530.5	294.7	22.4	12.009	575.0	189.17	96.10
3C	4/6/17	7:15	27.65	1956	93634	70.8	530.5	294.7	22.4	5.994	287.0	123.23	62.60
3C	4/6/17	7:20	27.65	1956	93634	70.8	530.5	294.7	22.4	0.752	36.0	29.33	14.90
3C	4/6/17	7:24	27.64	1955	93600	70.7	530.4	294.7	22.4	25.000	1197.0	297.24	151.00
3C	4/6/17	7:29	27.65	1956	93634	70.7	530.4	294.7	22.4	1.003	48.0	36.81	18.70
3C	4/6/17	7:33	27.65	1956	93634	70.8	530.5	294.7	22.4	0.501	24.0	21.26	10.80
3C	4/6/17	7:37	27.64	1955	93600	71.1	530.8	294.9	22.4	3.008	144.0	79.13	40.20
3C	4/6/17	7:42	27.64	1955	93600	71.3	531.0	295.0	22.4	0.146	7.0	7.05	3.58
4C	4/6/17	7:43	27.64	1955	93600	72.8	532.5	295.8	21.9	0.146	7.0	7.03	3.57
4C	4/6/17	7:47	27.64	1955	93600	72.9	532.6	295.9	21.9	3.008	144.0	75.98	38.60
4C	4/6/17	7:52	27.64	1955	93600	73.1	532.8	296.0	21.4	1.003	48.0	35.04	17.80
4C	4/6/17	7:56	27.64	1955	93600	73.5	533.2	296.2	21.3	25.000	1197.0	287.40	146.00
4C	4/6/17	8:01	27.64	1955	93600	73.5	533.2	296.2	21.3	2.047	98.0	59.25	30.10
4C	4/6/17	8:05	27.64	1955	93600	73.6	533.3	296.3	21.3	0.251	12.0	11.12	5.65
4C	4/6/17	8:10	27.64	1955	93600	73.6	533.3	296.3	21.3	5.994	287.0	120.67	61.30
4C	4/6/17	8:14	27.64	1955	93600	73.7	533.4	296.3	21.3	0.752	36.0	28.35	14.40
4C	4/6/17	8:18	27.64	1955	93600	72.4	532.1	295.6	21.3	0.501	24.0	20.47	10.40
4C	4/6/17	8:22	27.64	1955	93600	71.0	530.7	294.8	21.8	12.009	575.0	186.22	94.60
4C	4/6/17	8:26	27.64	1955	93600	69.8	529.5	294.2	22.4	0.146	7.0	6.75	3.43

Table B1. Concluded

Sample	Date	Time (PDT)	Atmospheric Pressure, *p*			Temperature, *T*			Relative Humidity, *RH*	Differential Pressure, Δ*p*		Permeability, *u*	
			(in. Hg)	(psf)	(Pa)	(°F)	(°R)	(K)	(%)	(psf)	(Pa)	($ft^3/ft^2/min$)	($cm^3/cm^2/s$)
5C	4/6/17	8:27	27.64	1955	93600	72.8	532.5	295.8	21.9	0.146	7.0	7.26	3.69
5C	4/6/17	8:31	27.64	1955	93600	72.9	532.6	295.9	21.9	0.251	12.0	11.91	6.05
5C	4/6/17	8:36	27.64	1955	93600	73.1	532.8	296.0	21.4	0.501	24.0	21.85	11.10
5C	4/6/17	8:40	27.64	1955	93600	73.5	533.2	296.2	21.3	0.752	36.0	30.31	15.40
5C	4/6/17	8:45	27.64	1955	93600	73.5	533.2	296.2	21.3	1.003	48.0	37.40	19.00
5C	4/6/17	8:49	27.64	1955	93600	73.6	533.3	296.3	21.3	2.047	98.0	62.60	31.80
5C	4/6/17	8:53	27.64	1955	93600	73.6	533.3	296.3	21.3	3.008	144.0	81.30	41.30
5C	4/6/17	8:57	27.64	1955	93600	73.7	533.4	296.3	21.3	5.994	287.0	126.77	64.40
5C	4/6/17	9:02	27.64	1955	93600	72.4	532.1	295.6	21.3	12.009	575.0	195.67	99.40
5C	4/6/17	9:06	27.64	1955	93600	71.0	530.7	294.8	21.8	25.000	1197.0	307.09	156.00
5C	4/6/17	9:10	27.64	1955	93600	69.8	529.5	294.2	22.4	0.146	7.0	7.46	3.79

Appendix C. Effective Porosity Test Results

Table C1. Effective porosity test results. Sorted by increasing value of $\hat{Re}$.

$\hat{Re}$		c_e	$\hat{Re}$		c_e
(1/ft)	(1/m)		(1/ft)	(1/m)	
6.557E+04	2.151E+05	0.01002	8.639E+04	2.834E+05	0.01255
6.557E+04	2.151E+05	0.01035	8.640E+04	2.835E+05	0.01339
6.566E+04	2.154E+05	0.01043	8.645E+04	2.836E+05	0.01266
6.568E+04	2.155E+05	0.00953	8.647E+04	2.837E+05	0.01362
6.576E+04	2.158E+05	0.01006	1.213E+05	3.980E+05	0.01682
6.576E+04	2.158E+05	0.00956	1.215E+05	3.985E+05	0.01699
6.577E+04	2.158E+05	0.01069	1.215E+05	3.987E+05	0.01577
6.579E+04	2.158E+05	0.01005	1.216E+05	3.990E+05	0.01578
6.580E+04	2.159E+05	0.01006	1.217E+05	3.994E+05	0.01702
6.582E+04	2.159E+05	0.01077	1.218E+05	3.997E+05	0.01611
6.584E+04	2.160E+05	0.01085	1.219E+05	3.998E+05	0.01640
6.584E+04	2.160E+05	0.01020	1.220E+05	4.002E+05	0.01655
6.589E+04	2.162E+05	0.01014	1.220E+05	4.003E+05	0.01640
6.590E+04	2.162E+05	0.01039	1.221E+05	4.004E+05	0.01701
6.591E+04	2.162E+05	0.01010	1.221E+05	4.005E+05	0.01658
6.591E+04	2.163E+05	0.01026	1.222E+05	4.008E+05	0.01613
6.592E+04	2.163E+05	0.01113	1.222E+05	4.008E+05	0.01717
6.594E+04	2.163E+05	0.01035	1.222E+05	4.010E+05	0.01626
6.594E+04	2.163E+05	0.01019	1.223E+05	4.012E+05	0.01720
6.597E+04	2.164E+05	0.01025	1.484E+05	4.868E+05	0.01780
6.598E+04	2.165E+05	0.01037	1.484E+05	4.870E+05	0.01904
6.599E+04	2.165E+05	0.01103	1.490E+05	4.889E+05	0.01785
6.602E+04	2.166E+05	0.01057	1.491E+05	4.890E+05	0.01923
6.603E+04	2.166E+05	0.01116	1.492E+05	4.895E+05	0.01824
6.604E+04	2.167E+05	0.00965	1.494E+05	4.900E+05	0.01860
6.604E+04	2.167E+05	0.01066	1.494E+05	4.902E+05	0.01921
6.604E+04	2.167E+05	0.01033	1.494E+05	4.903E+05	0.01847
6.606E+04	2.167E+05	0.01095	1.494E+05	4.903E+05	0.01911
6.607E+04	2.168E+05	0.01122	1.495E+05	4.903E+05	0.01863
6.625E+04	2.174E+05	0.01092	1.495E+05	4.905E+05	0.01872
8.568E+04	2.811E+05	0.01210	1.496E+05	4.907E+05	0.01900
8.583E+04	2.816E+05	0.01296	1.497E+05	4.910E+05	0.01886
8.597E+04	2.821E+05	0.01301	1.497E+05	4.910E+05	0.01938
8.606E+04	2.823E+05	0.01202	1.497E+05	4.912E+05	0.01911
8.610E+04	2.825E+05	0.01311	1.714E+05	5.624E+05	0.02035
8.620E+04	2.828E+05	0.01269	1.716E+05	5.629E+05	0.01907
8.620E+04	2.828E+05	0.01258	1.720E+05	5.644E+05	0.02062
8.630E+04	2.831E+05	0.01265	1.722E+05	5.648E+05	0.01889
8.631E+04	2.832E+05	0.01333	1.723E+05	5.654E+05	0.02008
8.632E+04	2.832E+05	0.01272	1.724E+05	5.657E+05	0.01986
8.636E+04	2.833E+05	0.01299	1.725E+05	5.659E+05	0.01946

Table C1. Concluded.

$\hat{Re}$		c_e
(1/ft)	(1/m)	
1.725E+05	5.660E+05	0.02061
1.726E+05	5.663E+05	0.02008
1.727E+05	5.667E+05	0.02023
1.728E+05	5.669E+05	0.02076
1.729E+05	5.672E+05	0.02012
1.729E+05	5.673E+05	0.01978
1.730E+05	5.675E+05	0.02042
1.730E+05	5.675E+05	0.02087
2.449E+05	8.034E+05	0.02383
2.449E+05	8.036E+05	0.02256
2.457E+05	8.061E+05	0.02405
2.459E+05	8.069E+05	0.02261
2.465E+05	8.086E+05	0.02318
2.465E+05	8.086E+05	0.02396
2.466E+05	8.091E+05	0.02315
2.467E+05	8.092E+05	0.02309
2.467E+05	8.093E+05	0.02352
2.468E+05	8.096E+05	0.02371
2.468E+05	8.097E+05	0.02354
2.468E+05	8.097E+05	0.02409
2.469E+05	8.100E+05	0.02319
2.473E+05	8.112E+05	0.02378
2.485E+05	8.154E+05	0.02422
2.968E+05	9.738E+05	0.02553
2.973E+05	9.754E+05	0.02388
2.978E+05	9.769E+05	0.02567
2.983E+05	9.786E+05	0.02380
2.983E+05	9.788E+05	0.02498
2.985E+05	9.795E+05	0.02484
2.986E+05	9.797E+05	0.02491
2.988E+05	9.802E+05	0.02559
2.988E+05	9.804E+05	0.02440
2.990E+05	9.809E+05	0.02509
2.990E+05	9.810E+05	0.02577
2.994E+05	9.821E+05	0.02516
2.995E+05	9.825E+05	0.02451
2.998E+05	9.835E+05	0.02539
3.003E+05	9.851E+05	0.02579
4.189E+05	1.374E+06	0.02820
4.190E+05	1.375E+06	0.02684
4.208E+05	1.380E+06	0.02682
4.210E+05	1.381E+06	0.02843
4.216E+05	1.383E+06	0.02730
4.218E+05	1.384E+06	-
4.219E+05	1.384E+06	0.02827
4.219E+05	1.384E+06	0.02749
4.220E+05	1.384E+06	0.02766
4.222E+05	1.385E+06	0.02837
4.223E+05	1.385E+06	0.02754
4.224E+05	1.386E+06	0.02772
4.226E+05	1.386E+06	0.02721
4.230E+05	1.388E+06	0.02838
4.232E+05	1.389E+06	0.02810
5.948E+05	1.952E+06	0.03079
5.953E+05	1.953E+06	0.02914
5.963E+05	1.956E+06	0.02969
5.968E+05	1.958E+06	0.02934
5.969E+05	1.958E+06	0.03070
5.971E+05	1.959E+06	0.02981
5.972E+05	1.959E+06	0.03029
5.977E+05	1.961E+06	0.03041
5.978E+05	1.961E+06	0.03061
5.980E+05	1.962E+06	0.02991
5.981E+05	1.962E+06	0.03082
5.981E+05	1.962E+06	0.02997
5.985E+05	1.964E+06	0.03109
5.987E+05	1.964E+06	0.03104
5.989E+05	1.965E+06	0.03053
8.560E+05	2.808E+06	0.03131
8.595E+05	2.820E+06	0.03138
8.610E+05	2.825E+06	0.03248
8.611E+05	2.825E+06	0.03353
8.612E+05	2.825E+06	0.03331
8.613E+05	2.826E+06	0.03187
8.617E+05	2.827E+06	0.03247
8.619E+05	2.828E+06	0.03336
8.622E+05	2.829E+06	0.03253
8.625E+05	2.830E+06	0.03274
8.626E+05	2.830E+06	0.03248
8.630E+05	2.831E+06	0.03228
8.635E+05	2.833E+06	0.03340
8.639E+05	2.834E+06	0.03315
8.661E+05	2.842E+06	0.03366

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14. ABSTRACT
In response to a NASA request, Heathcoat Fabrics Limited has woven a new parachute fabric (Custom Design 1 G-60315-1800-Q01). This fabric was tested to obtain its permeability in air (i.e., flow-through volume of air per area per time) over a range of differential pressures from 0.146 to 25 psf (7 to 1197 Pa). The fabric met its specification permeability of 60 to 100 ft3/ft2/min (30.5 to 50.8 cm3/cm2/s) at the U.S. standard differential pressure of 0.5 inch of water (2.60 psf, 124 Pa). The permeability results were transformed into an effective porosity model for use in calculations related to the total porosity of parachutes. The tested fabric is being considered for use in parachutes for future missions to Mars. Calculations of drag coefficient were performed for two geometrically identical parachutes using either the new fabric or fabric woven to Parachute Industry Specification PIA-C-7020D Type I (Mars Science Laboratory Disk-Gap-Band parachute operating on Mars at a Mach number of 0.41). These calculations indicate essentially no difference in the drag coefficient between the two parachutes.

15. SUBJECT TERMS
Fabric; Fabric permeability; Parachute; Permeability

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