A Model of Seam Pucker and its Implementation. Part II: Experimental

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This paper compares the numerical assessment of pucker, derived from the model developed in part I, with visual assessments of the phenomenon. It is shown that there is good linear correlation between the two. The model is then used to evaluate which of a selection of stiffeners is needed to reduce pucker to an acceptable level.

Keyword: Seam deformation, pucker severity, garment appearance, garment manufacturing

Introduction

In Part I, we introduced a simplified model of a lock stitch (301) seam, and used it to develop a numerical measure of the severity of puckering in the seam. This measure was called "relative pucker" and is a combination of the factors liable to affect the appearance and properties of the seam. The non-dimensional nature of this method, when compared to that of maximum deflection, makes calculations easier. In what follows the suffixes n and b are used to denote quantities related to the needle and bobbin threads and fabrics. Thus if

t_n, t_b are the fabric thicknesses.
B_n, B_b are the fabric bending rigidities per unit width.
d_n, d_b are the thread diameters,
b_n, b_b are the thread bending rigidities.
T_n, T_b are the tensions in the threads as they lie in the relaxed seam.
the relative pucker is given by

$$\boldsymbol{R_p = \frac{|T_n - T_b| l^3}{192\, B_e H}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

where l is the stitch length and

$$\boldsymbol{B_e = B_n d_n + B_b d_b + b_n + b_b},$$
$$H = t_n + t_b + d_n + d_b.$$

In Part-II we investigate how relative pucker relates to the conventional visual assessment of pucker and discuss a practical application of the new measure. To this end 18 lightweight woven fabrics, ranging in weight from 43 gm^{-2} to 160 gm^{-2} and labeled F_1 to F_{18} , were stitched using one of two sewing threads , labeled T_1 and T_2. Each seam stitched two pieces of the same fabric and the same thread was used as both needle and bobbin thread. Thus in equation (2) the suffixes can be omitted and the equations become

$$B_e = 2(Bd + b)$$
$$H = 2(t + d)$$

The stitch length used was 2 mm for all seams.

The visual assessment of pucker

A visual assessment procedure has been devised by the American Association of Textile Chemists and Colorists (AATCC-88B) [1]. In this procedure three observers compare three specimens of a particular seam with a series of five photographs of increasingly severely puckered seams, numbered 5 to 1. Grade 5 is given to a sample with no puckering while a seam with very severe puckering is graded 1. Figure 1 shows an example of the set-up of the five standards and three samples of one of our experimental seams.

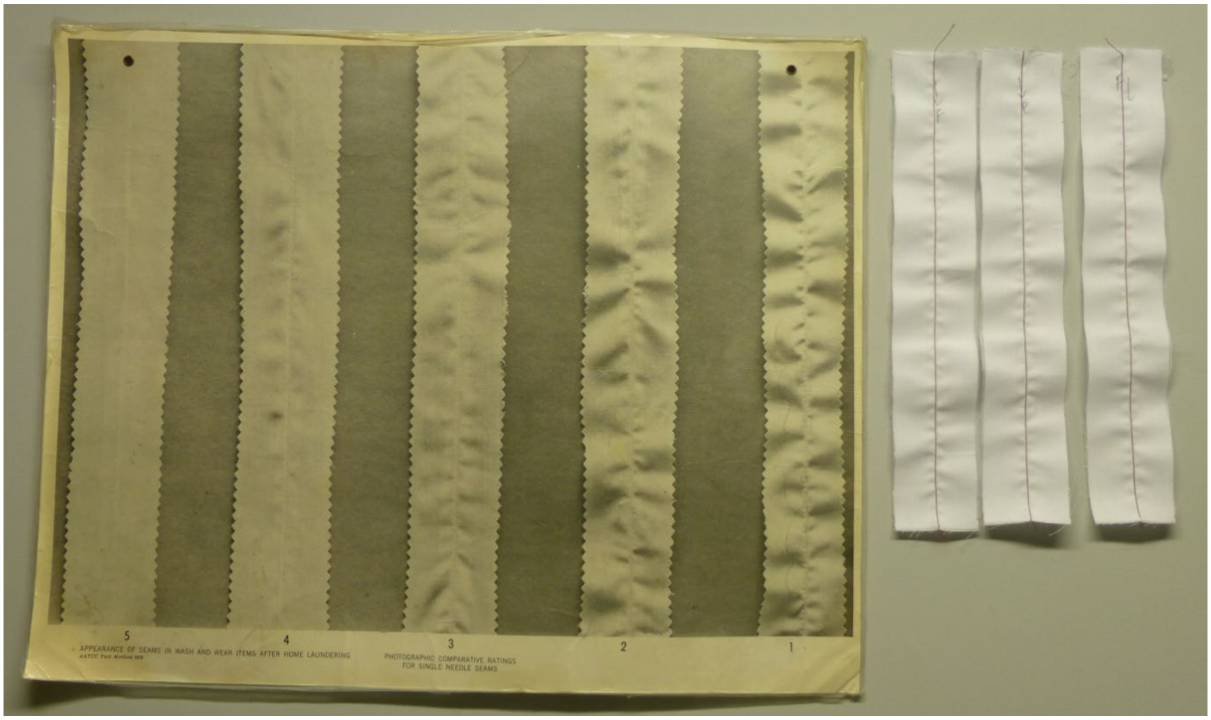

Figure 1 An example of visual assessment set-up

(Incidentally the average grade for these particular seams was 1.7). This procedure was used to assess visually the seams produced using threads T_1 and T_2 to stitch all eighteen fabrics, i.e. there were 36 seams in all.

Properties of the experimental materials

a) Threads

The two threads involved in the experiments wereT_1, a polyester /cotton core spun thread and T_2, a 100% polyester core spun thread. Their diameters (d) were assessed microscopically at twenty points along the thread. The mean diameters are given in Table 1. Also shown are the values of the thread bending rigidities (b) that were evaluated using the KES-FB2 tester [2]. The table shows the mean of five tests.

Table 1 Thread properties

Thread	T_1	T_2
Mean diameter (cm)	0.0436	0.0236
Mean Bending rigidity $(g_f.cm^2)$	$4.1x10^{-3}$	$1.2x10^{-3}$

b) Fabrics

The fabric properties involved in equations (1) - (5) are their thicknesses and their bending rigidities. Fabric thickness was estimated using a FAST compression tester [3], while the bending rigidities were measured using the same KES-FB2 tester employed to measure the thread bending rigidities. The fabrics are of thin shirting hardly compressible material. Table 2 gives the mean of five tests in each case.

Table 2 Fabric properties

Fabric	Thickness (cm)	Bending rigidity $(g_f.cm^2/cm)$	Fabric	Thickness (cm)	Bending rigidity $(g_f.cm^2/cm)$
F_1	0.0283	0.0480	F_{10}	0.0403	0.4660
F_2	0.0339	0.0420	F_{11}	0.0294	0.0428
F_3	0.0474	0.1135	F_{12}	0.0273	0.0415
F_4	0.0340	0.2290	F_{13}	0.0271	0.0635
F_5	0.0278	0.0565	F_{14}	0.0442	0.1140
F_6	0.0408	0.0525	F_{15}	0.0315	0.0435
F_7	0.0476	0.1240	F_{16}	0.0379	0.0815
F_8	0.0096	0.0970	F_{17}	0.0384	0.0232
F_9	0.0333	0.0196	F_{18}	0.0225	0.0050

The estimation of $T_n - T_b$

The final quantity needed to calculate the relative pucker value for each seam is the tension difference $T_n - T_b$ in the needle and bobbin threads as they lie in the relaxed seam. A technique for estimating this difference was described in Part-I, resulting in the equation

$$T_n - T_b \cong \frac{X_n - X_b}{1 + \varepsilon_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where X_n and X_b are the total forces needed to extend a strip of fabric /seam to an extension of size ε_c when (a) the needle thread is clipped (X_n) and (b) when the bobbin thread is clipped(X_b). In each test the width of the specimen tested must be identical. In this investigation the three samples employed in the visual assessment were used as test specimens. They were extended using an Instron Tensile Tester equipped with a load cell of 10N capacity. The gauge length was 270 mm and the rate of extension 1 cm per minute. One of the three specimens was tested with the needle and bobbin threads intact, one with the needle thread clipped and one with a clipped bobbin thread. Typical results are illustrated in figures 2 and 3, which show the load extension curves for fabric F_1 stitched by threads T_1 and T_2 respectively.

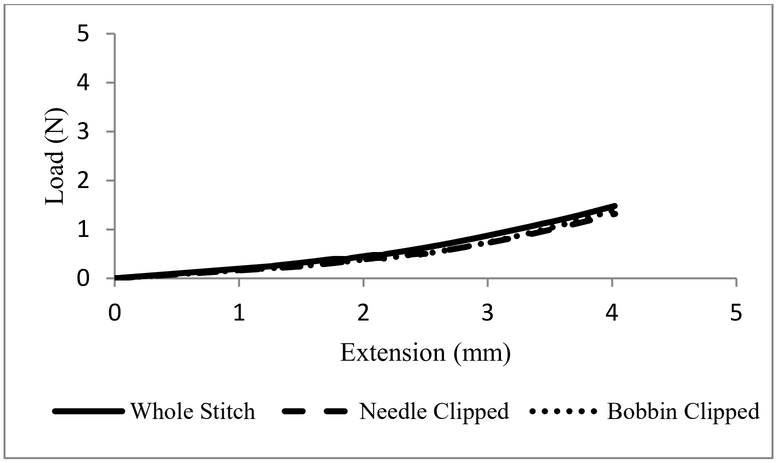

Figure 2 Load-extension curves of fabric F_1, stitched by thread T_1

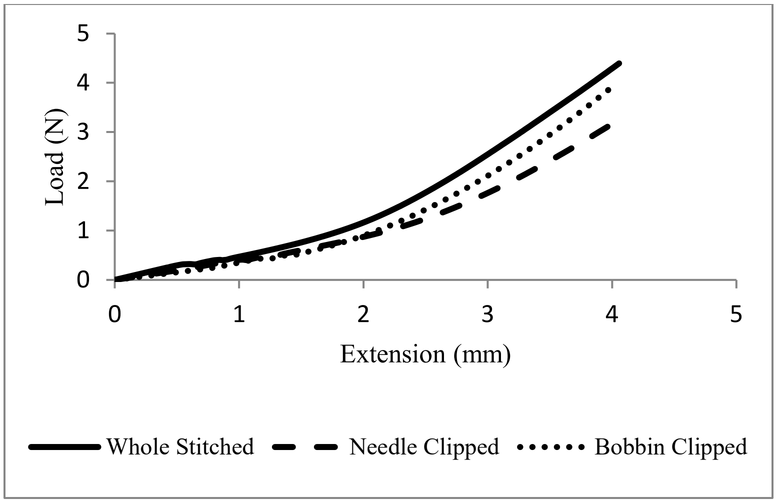

Figure 3 Load extension curves of fabric F_1, stitched by thread T_2

To estimate $T_n - T_b$ the loads when the seam had been extended by 2 mm (i.e. when $\varepsilon_c = \frac{2}{270} = 0.007407$) were chosen as X_n and X_b. Thus equation (6) becomes

$$|T_n - T_b| = \frac{|X_n - X_b|}{1.007407}$$

The results are shown in Table 3 and 4.

Table 3a Fabrics stitched with thread T_1

Fabric	X_n (g_f)	X_b (g_f)	$\lvert T_n - T_b \rvert$ (g_f)	Fabric	X_n (g_f)	X_b (g_f)	$\lvert T_n - T_b \rvert$ (g_f)
F_1	82.5	70.4	12.01	F_{10}	320.4	301.1	19.16
F_2	53.5	43.6	9.86	F_{11}	136.3	120.3	15.88
F_3	30.4	118.8	11.5	F_{12}	98.2	85.8	12.31
F_4	102.1	91.7	10.32	F_{13}	112.3	109.9	2.38
F_5	125.8	100.8	24.82	F_{14}	232.1	223.7	8.34
F_6	65.7	64.7	1.00	F_{15}	97.2	76.9	20.15
F_7	242.3	244.6	2.28	F_{16}	126.9	103.5	23.23
F_8	77.4	89.9	12.41	F_{17}	26.8	28.3	1.49
F_9	54.2	54.2	0.00	F_{18}	38.5	38.7	0.20

Table 3(b) Fabrics stitched with thread T_2

Fabric	X_n (g_f)	X_b (g_f)	$\lvert T_n - T_b \rvert$ (g_f)	Fabric	X_n (g_f)	X_b (g_f)	$\lvert T_n - T_b \rvert$ (g_f)
F_1	90	87.8	2.18	F_{10}	0	0	0
F_2	75.8	67.3	8.44	F_{11}	144.6	150.4	5.76
F_3	129.5	133.3	3.77	F_{12}	134	115.5	18.36
F_4	104.3	95.9	8.34	F_{13}	183.6	161.5	21.94
F_5	100.6	75.6	24.82	F_{14}	266.9	271.5	4.57
F_6	112.2	94.5	17.57	F_{15}	111.4	104.1	7.25
F_7	217.9	222.2	4.27	F_{16}	205.5	209.1	3.57
F_8	328.5	294.9	33.85	F_{17}	30.9	32.8	1.89
F_9	33.6	32.7	0.89	F_{18}	68.6	66.7	1.89

Comparison of Relative Pucker with Visual Grades

Using the information given in Table 1-4, we are now able to calculate the values of relative pucker (R_p) from equations (1 -2a). The results are shown in Table 4 together with the mean visual pucker grades (P).

Table 4 Values of relative pucker (R_p) and average visual grade (P)

a) Fabrics sewn with thread T_1

Fabric	R_p	P	Fabric	R_p	P
F_1	0.28	2.9	F_{10}	0.10	4.0
F_2	0.22	2.6	F_{11}	0.38	2.1
F_3	0.15	3.5	F_{12}	0.31	2.3
F_4	0.10	3.7	F_{13}	0.05	3.5
F_5	0.55	1.7	F_{14}	0.11	3.3
F_6	0.02	3.7	F_{15}	0.47	2.3
F_7	0.03	3.7	F_{16}	0.39	3.0
F_8	0.29	2.8	F_{17}	0.04	3.3
F_9	0.00	3.6	F_{18}	0.01	3.5

b) Fabrics sewn with thread T_2

Fabric	R_p	P	Fabric	R_p	P
F_1	0.19	3.3	F_{10}	0.00	4.7
F_2	0.70	3.0	F_{11}	0.51	3.0
F_3	0.14	4.5	F_{12}	1.72	2.7
F_4	0.23	4.0	F_{13}	1.67	2.5
F_5	1.99	2.5	F_{14}	0.18	3.7
F_6	1.17	3.0	F_{15}	0.62	3.0
F_7	0.15	4.0	F_{16}	0.19	4.0
F_8	3.04	1.0	F_{17}	0.18	3.7
F_9	0.10	3.7	F_{18}	0.24	3.3

The results in Tables 4 (a) and (b) are plotted in Figures 3(a) and 3(b)

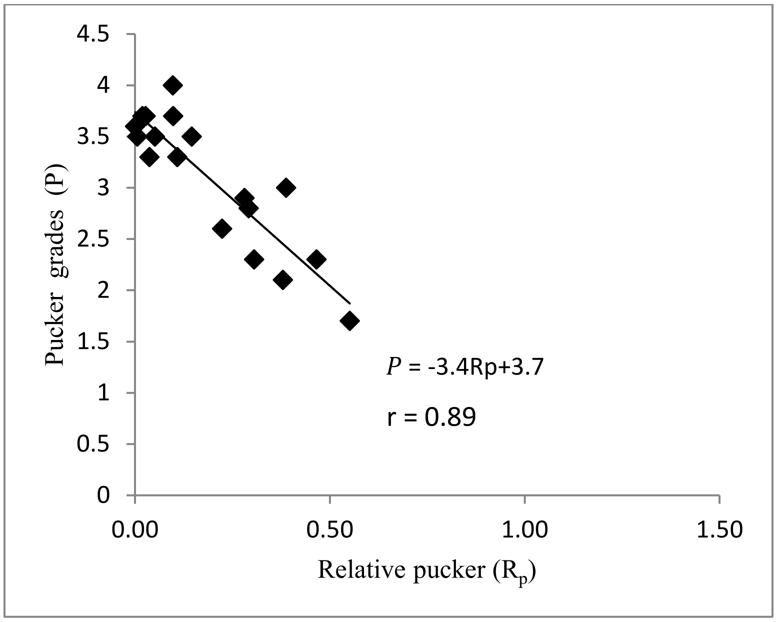

Figure 3a Relation between R_p and P for fabrics stitched with sewing thread T_1

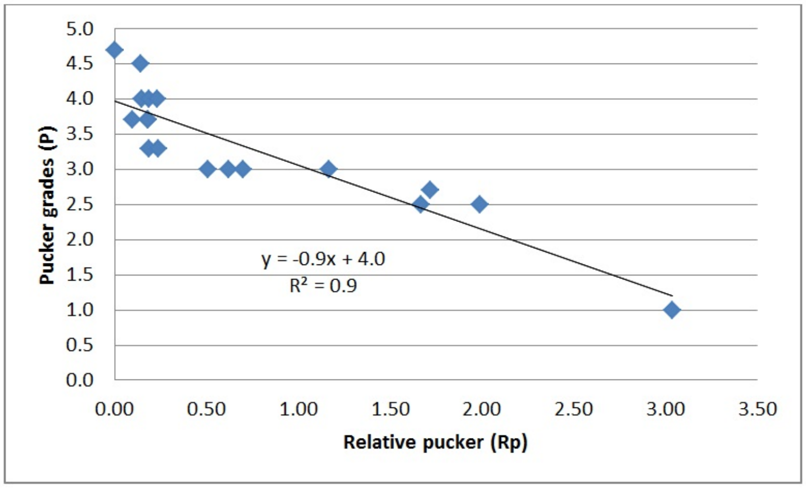

Figure 3(b) Relation between R_p and P for fabrics stitched with sewing thread T2

Both set of data exhibit a strong linear relation (the correlation coefficient $r \cong 0.9$in both cases), which suggests that the relative pucker index is a useful measure of the tendency of a seam to pucker. The seams sewn using thread T2 (Table 4(b) and figure 3(b)) exhibit a smaller range of values of visual assessment and a greater range of values of relative pucker; hence the smaller slope of the linear relation. Table 1 shows that T2 has a smaller diameter (d) and bending rigidity (b) than T1, a fact that would lead to smaller values of B_e and H (equations 2(a)) and thus a tendency to produce large values of R_p in equation (1), though T_n and T_b will presumably also be affected by these and other properties of the threads and fabrics as suggested by equation (8) of Part I.

An application of R_p: stiffeners

It is conventional to regard a seam whose visual rating P is less than 3 as unsatisfactory, and one method used in practice to reduce the incidence of pucker is to introduce a “stiffener” between the two fabrics being joined. This has the effect, so far as the value of R_p is concerned of increasing the thickness and bending rigidity of the “equivalent beam”, and thus reducing the value of R_p, which is equivalent to increasing that of P, i.e. reducing the pucker. If B_s and $t_s$are the bending rigidity per unit width and the thickness of the stiffener then B_e is increased to B_{es} and H to H_s, where

$$B_{es} = B_e + B_s d \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

And

$$H_s = H + t_s \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (5)$$

The value of R_p then becomes

$$R_{ps} = \frac{|T_n - T_b| l^3}{192\, B_{es} H_s} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (6)$$

The stiffener must be chosen so that R_{ps} is below a critical value R_{pc}, sufficiently small to ensure that $P \geq 3$.

The values of R_{pc} can be found from the regression equations shown in figure 3.

For seams sewn with T$_1$,

$$P = -3.4 R_p + 3.7$$

so that, when $P = 3,\ R_{pc} = 0.21$; and for seams sewn with T$_2$,

$$P = -0.9 R_p + 4.0$$

leading to $R_{pc} = 1.1$ when $P = 3$.

Now, from (1) and (6) we find that

$$R_{ps} = \frac{Be}{B_{es}} \frac{H}{H_s} R_p \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (7)$$

if it is assumed that $|\boldsymbol{T_n} - \boldsymbol{T_b}|$ and l remain unchanged when the stiffener is introduced.

Four stiffeners were available for the present investigation, whose relevant properties are shown in Table 5.

Table 5 Stiffener properties

Stiffener	B_s $(g_f.cm^2/cm)$	t_s (cm)
S_1	0.0774	0.007
S_2	0.1674	0.011
S_3	0.2574	0.014
S_4	0.4125	0.017

The values of B_s and $t_s$shown were obtained using the same techniques as we used to estimate those of the test fabrics F_1-F_{18}.

The procedure adopted to decide which stiffener was appropriate for a particular seam may be exemplified by considering fabric F_{15} sewn by the thread T_1. The original visual pucker grade for this seam was 2.3, and its $R_p$value was 0.47. The value of B_e and H were $0.012\ g_f.cm^2/cm$ and $0.1502\ cm$ respectively, calculated using equation (2(f)) and the thread and fabric properties shown in Table 1 and 2. Thus for stiffener S_1, equations (4) and (5) give

$$B_{es} = 0.0120 + 0.0774\text{x}0.0436 = 0.0154\ \text{gf.cm}^2/\text{cm}$$

$$H_s = 0.1502 + 0.007 = 0.1572\ cm$$

Hence from equation (7) we find

$$R_{ps} = \frac{0.0120}{0.0154}\frac{0.1502}{0.1572}.0.47 = 0.35$$

which is still above the critical value of 0.21. Moving on to the other stiffeners in succession, Table 6 can be generated.

Table 6 Calculation of $\boldsymbol{R_{ps}}$for F_{15}/T_1

Stiffener	S_1	S_2	S_3	S_4
B_sd	0.0034	0.0073	0.0112	0.0180
$B_{es} = 0.0120 + B_sd$	0.0154	0.0193	0.0232	0.0300

$H_s = 0.1520 + t_s$	0.1572	0.1612	0.1642	0.1672
R_{ps}	0.35	0.27	0.22	0.17

It can be seen that as the stiffener becomes more “robust’’ (S_1→S_4) the value of R_{ps} decreases. Its value of 0.22 when S_3 is used is very close to the critical value and would probably give satisfactory results. Strictly though, the method indicates that S_4 should be used.

Tables 4(a) and (b) show that seven seams sewn by T_1 and four sewn by T_2 had pucker grades less than 3, and were therefore candidates for the introduction of a stiffener. Table7 shows these cases, their $R_p$values before stiffening, the stiffeners suggested by the above procedure, and the visual grades after the introduction of the appropriate stiffener. As can be seen, the visual grades for all the stiffened seams where, as expected, greater than 3.

Table 7 The effect of stiffeners

(a) Seams sewn using T_1

Fabric	Grade P	Original R_p	Suggested Stiffener	Stiffened R_p	Revised P
F_1	2.9	0.28	S_1	0.18	5.0
F_2	2.6	0.23	S_1	0.17	4.9
F_5	1.7	0.55	S_4	0.21	4.7
F_8	2.8	0.29	S_2	0.18	5.0
F_{11}	2.1	0.38	S_2	0.22	5.0
F_{12}	2.3	0.30	S_1	0.28	5.0
F_{15}	2.3	0.47	S_4	0.17	5.0

(b) Seams sewn using T_2

Fabric	Grade P	Original R_p	Suggested Stiffener	Stiffened R_p	Revised P
F_5	2.5	1.99	S_2	1.01	5.0
F_8	1.0	3.04	S_4	1.01	5.0
F_{12}	2.7	1.72	S_2	0.81	5.0
F_{13}	2.5	1.67	S_2	0.86	5.0

The art of stiffening has been practiced for decades, being prominent in shirts, where collars and cuffs are fused. The work by Stylios (4) for Marks and Spencer Plc in the 80's established the mechanism of seam pucker and the interaction of fabric, thread and sewing machine mechanisms and in the 90's stiffening became part of the production of non-iron shirts (5). This work encapsulates all of that by a simple model and it shows for the first time how a manufacturer may choose the appropriate stiffener for eliminating seam pucker. Although this work is on stitching of fabrics, it can be applied to the joining of other materials such as composites.

Conclusion

A simple theory for assessing the degree of puckering in a seam has been presented and shown to correlate well with standard visual assessments of the phenomenon. The theory has been used successfully to select appropriate stiffeners in cases when the original seam was unsatisfactory.

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