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Evaluation of Kevlar-29 vs Nylon for 3.81 m (12.5 ft) Diam Ribbon Parachutes

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A series of 12 sled-launched tests were conducted to evaluate the suitability of Kevlar-29 as a replacement for nylon in parachute construction. Kevlar-29 was found to be a suitable replacement for nylon in parachute construction with an attendant 50% saving in weight and volume. However, different design techniques than those used for all-nylon parachutes were found to be necessary when horizontal ribbons made of Kevlar-29 were used.

Nomenclature

C_D = parachute drag coefficient based on S (dimensionless)
D = parachute constructed diameter = 12.5 m
g_{max} = maximum deceleration, g
ΔP = pressure inside canopy-pressure outside canopy, kN/m^2
q = dynamic pressure = $\frac{1}{2}\rho V^2$, kN/m^2
r = radius of curvature of ribbon, m
t_{fill} = parachute filling time, s
s = ribbon stress, N/m^2
S = parachute constructed area = $\Pi/4\, D^2$, m^2
V = vehicle velocity, m/s
γ = angle between trajectory and horizontal
δ = air density, kg/m^3
ΔC_P = (pressure inside canopy-pressure outside) /q(dimensionless)

Subscripts

x = along track axis
z = perpendicular to sled track
i = impact

Introduction

NYLON has been used successfully as the primary construction material for parachutes since World War II as described in Ref. 1. A new synthetic polyamide fiber, Kevlar-29, developed by Du Pont, having 2.6 times the strength-to-weight ratio of nylon 66 has become available. Kevlar-29, described in detail in Ref. 2, has an ultimate fiber tensile strength of over 2.8×10^6kN/m^2 (400,000 psi) as compared with 8.0×10^5kN/m^2 (117,000 psi) for nylon 66. Elongation is about 4%, being much stiffer than nylon, which has 25% elongation. The specific gravity of Kevlar-29 is 1.44 as compared with 1.14 for nylon 66.

Exploratory wind tunnel tests[3,4] of 1.9 m (6.4 ft) diameter ribbon parachutes made of various combinations of nylon and Kevlar-29 indicated that about 50% saving in weight and pack volume could be achieved by using Kevlar-29 for parachute construction instead of nylon. Since the wind tunnel parachute deployments described above are for the infinite mass case, it was believed that free-flight tests should be conducted to evaluate the Kevlar-29 versus nylon under dynamic deceleration conditions. Of particular interest was the comparison of maximum deceleration and associated suspension line loads which were expected to be higher for Kevlar-29 as a result of its much lower elongation.

Considerable data[5] were available on performance of a 3.81 m (12.5 ft) ribbon parachute made of nylon, so this parachute design was selected. Initial intent was to use Kevlar-29 in construction of the 3.81 m parachutes using the same geometric layout and the same webbing strengths as the nylon design. A total of 12 free-flight deployment tests were conducted over a dynamic pressure range of 49.3 kN/m^2 (1030 lb/ft^2) to 99.6 kN/m^2 (2080 lb/ft^2) using first an all-nylon parachute and then one made entirely of Kevlar-29. As the tests progressed, it was found that, in making the Kevlar parachutes, the geometric design of the canopy had to be changed to obtain performance similar to the nylon canopy. Results from 12 tests are presented.

Test Method

A 1524 m (5000 ft) long dual-rail sled track[6] in Sandia Laboratories Area III test area at Albuquerque, N. Mex., was used to launch the test vehicles. A two-stage sled system shown in Fig. 1 was used. The first stage was powered by 25 12.7 cm (5 in.) diameter HVAR rockets and the second stage by 9 additional HVARs.

After the sled has reached the desired speed on the tract, the vehicle is ejected upward at approximately 21.3 m/s (70 ft/s) by a piston/cylinder driven by compressed gas. Parachute deployment is initiated by a switch† sensing a dynamic pressure[7] of 57.5kN/m^2 (1200 lb/ft^2) or 95.8 kN/m^2 (2000 lb/ft^2) through an orifice in the vehicle nose. A timer is used as backup in case the dynamic pressure switch fails. The dynamic pressure switch fired two thrusters powered by TC-21 gas generators. The thrusters eject the tail lid aft at about 12.2 m/s (40 ft/s) deploying a 7.1 cm (18 in.) diameter guide surface pilot chute. The pilot chute deploys the main parachute bag.

An 11-channel telemetry system in the vehicle is used to measure the following:

Three each longitudinal acceleration (+150, −50 g), ram pressure‡ [0–345 kN/m^2 (50 psia)], pressure switch monitor, separation monitor, camera monitor, clock monitor, noise monitor, tail-lid fire signal, and programmer output.

A laser tracker was used to obtain camera coverage of parachute deployment and inflation. Position data are also

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†Custom Component Switches, Inc., Part No. P96980-002, set for operation at 155 or 228 kN/m^2 (22.5 or 33 psia).

‡Statham Instruments, Inc., Model No. PA4042-100.

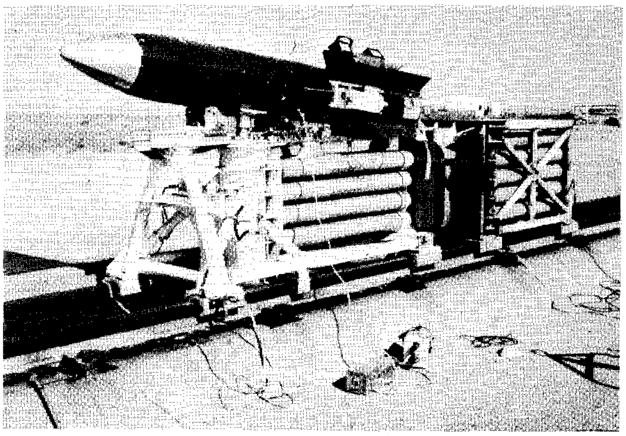


Fig. 1 Two-stage sled with test vehicle during prelaunch checkout.

obtained from the laser, which is reduced to obtain velocity vs time.

Parachute Test Vehicle

The sled launched adaptive test vehicle was designed for free-flight deployment testing of small parachutes. The parachute test vehicle sketch is shown in Fig. 2. The vehicle is 5.5 cm (14 in.) in maximum diameter and 11 m (108 in.) long. The vehicle weight can be adjusted between 181 and 272 kg (400 and 600 lb) (including parachute) by attaching ballast weights inside the vehicle. The parachute can is 25.4 cm (10 in.) in diameter and 1.17 m (46 in.) long with a volume of 0.059 m^3 (2.1 ft^3). A 0.32 cm (1/8 in.) diam orifice in the nose permits measurement of ram air pressure, and a pressure switch is used to obtain a signal to fire the two thrusters deploying the tail lid. There are eight lugs at the vehicle midsection used to attach the parachute suspension lines. The telemetry can is forward of the lugs. Two photosonic cameras operated at 500 frames/s are mounted on housings 180 deg apart forward of the four stabilizing fins. The vehicle body is made of cast aluminum except for the nose, which is steel.

Parachute Design

The basic parachute design used for these tests was a 3.81 m (12.5 ft) diameter ribbon design.[5] This parachute has had over 500 successful deployments on drop tests from aircraft. Design details are listed in Appendix A.

The parachutes made of Kevlar-29 were manufactured by Goodyear Aircraft Corp., Akron, Ohio, under a contract with Sandia Laboratories using the U.S. Air Force drawings and specifications MIL-P-38019A, Amendment 2, dated May 23, 1967, as were the nylon parachutes mentioned above. Webbings made of Kevlar-29 were designed by Goodyear to match as closely as possible the existing nylon webbings used for this parachute. A comparison of webbing properties is given in Appendix B.

The all-nylon parachutes weighed 43 lb (19.5 kg) and the all-Kevlar-29 parachutes weighed approximately 20 lb (9.1 kg), indicating a weight saving of greater than 50% for Kevlar (see column 5 of Table 1). Parachute pack length was 50% less for the Kevlar as compared to nylon parachute.

Fig. 3 Vehicle and Kevlar-29 parachute after Test No. 5.

Test Results

A summary of data obtained from the 12 sled tests is given in Table 1. Three of the tests (1, 4, and 15) yielded no parachute data because the parachute was not deployed. Of the nine good tests, four were of entirely nylon parachutes, four were of entirely Kevlar-29 and one (No. 8) was a nylon canopy with Kevlar-29 suspension lines. A photograph of test vehicle 5 after impact is shown in Fig. 3.

Typical trajectory parameters obtained from the laser tracker for test 10 are shown in Fig. 4. Parameters shown are: 1) velocity, 2) dynamic pressure, 3) altitude vs time, 4) altitude vs range, and 5) drag coefficient vs Mach number. Longitudinal deceleration variation with time from sled launch is shown in Figs. 5–7 for all-Kevlar-29, all-nylon, and Kevlar-29 suspension lines with nylon canopy, respectively.

The maximum deceleration as a function of dynamic pressure at initiation of deployment is shown for all tests in Fig. 8. There is no discernable difference between the all-Kevlar-29 and the all-nylon parachutes since the data points fall within an expected scatter of ±10%. The canopy with nylon ribbons and Kevlar-29 suspension lines, which are continuous over the canopy, has lower peak deceleration (75 g as compared with 94 g for the all-nylon parachutes).

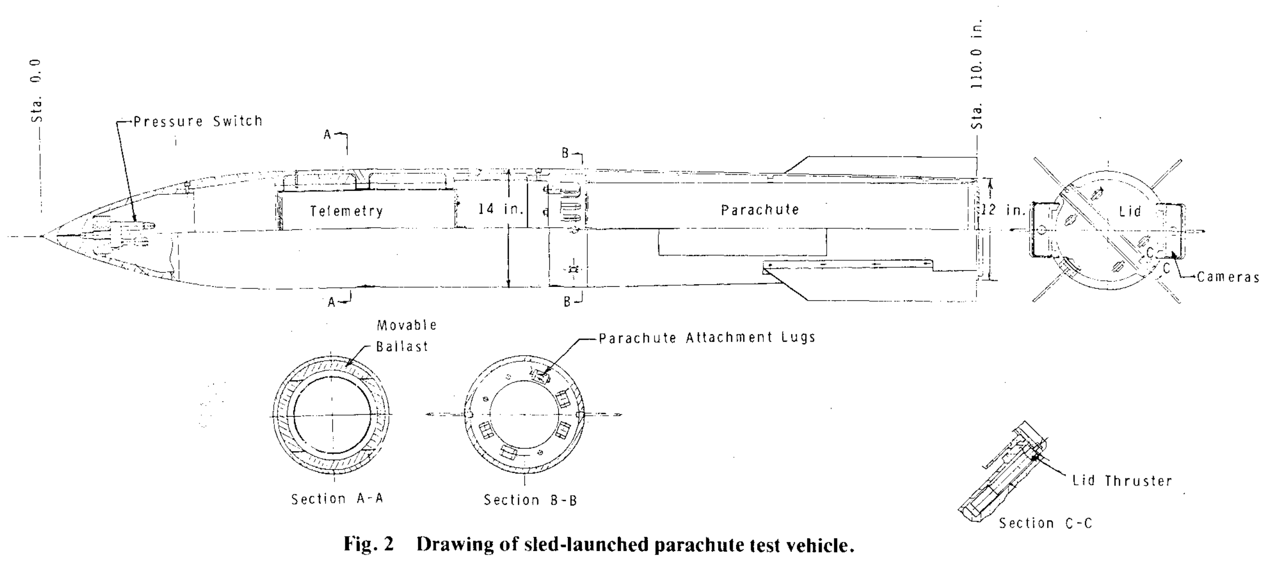
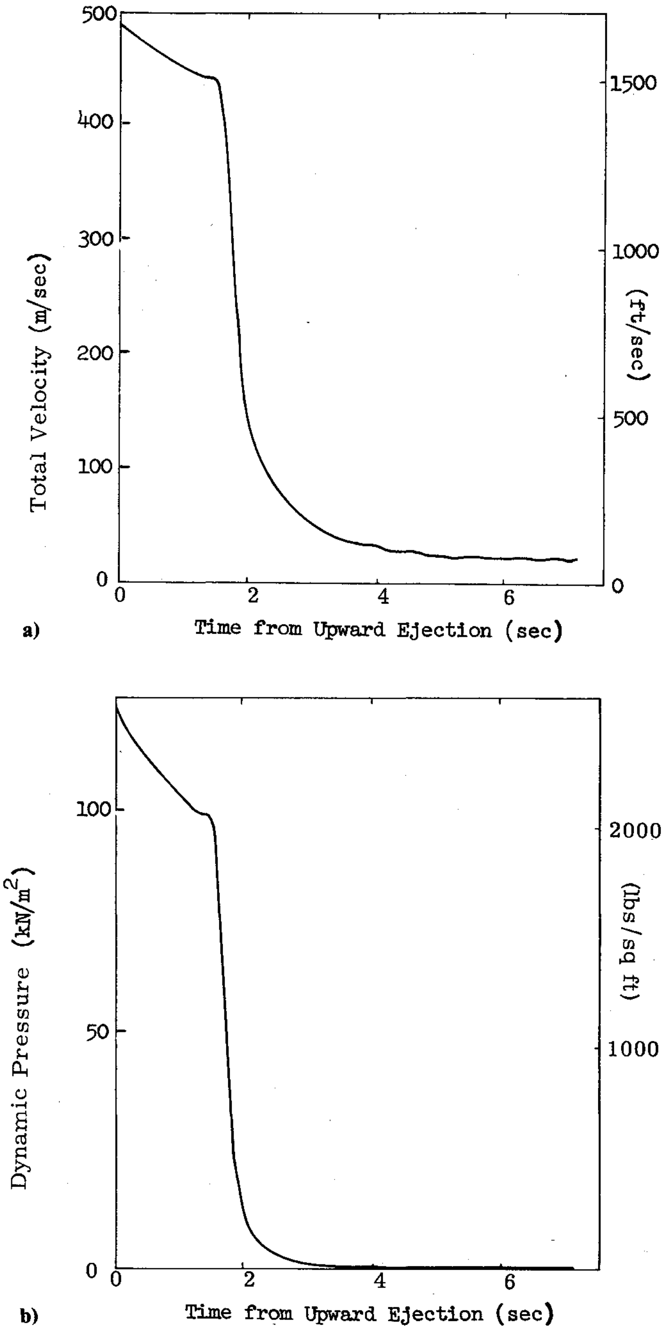


Fig. 2 Drawing of sled-launched parachute test vehicle.



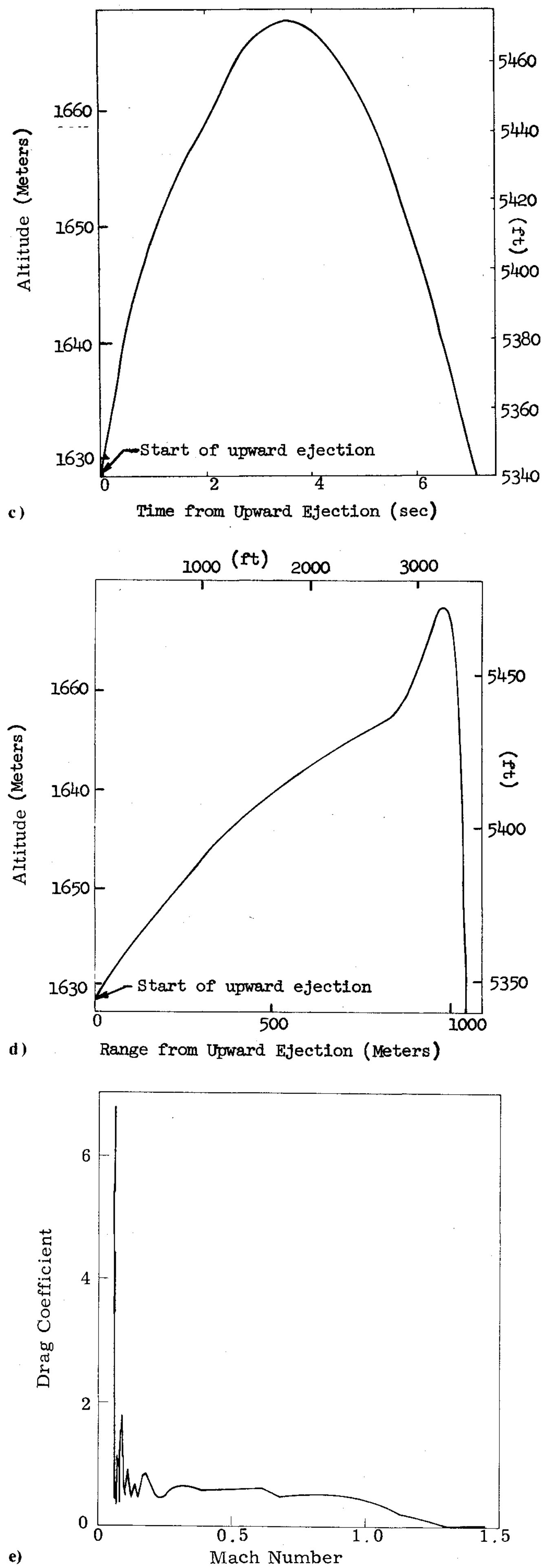


Fig. 4 Trajectory data from Test No. 10. a) Total velocity vs time from upward ejection. b) Dynamic pressure vs time from upward ejection. c) Altitude vs time from upward ejection. d) Altitude vs range from upward ejection. e) Drag coefficient vs Mach number.

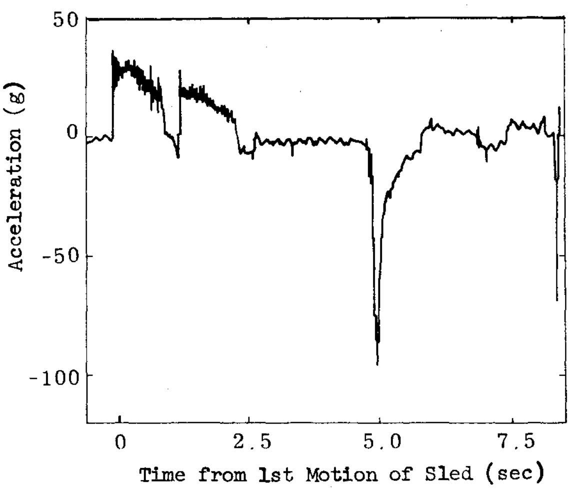


Fig. 5 Deceleration for all-Kevlar-29 parachute on Test No. 5.

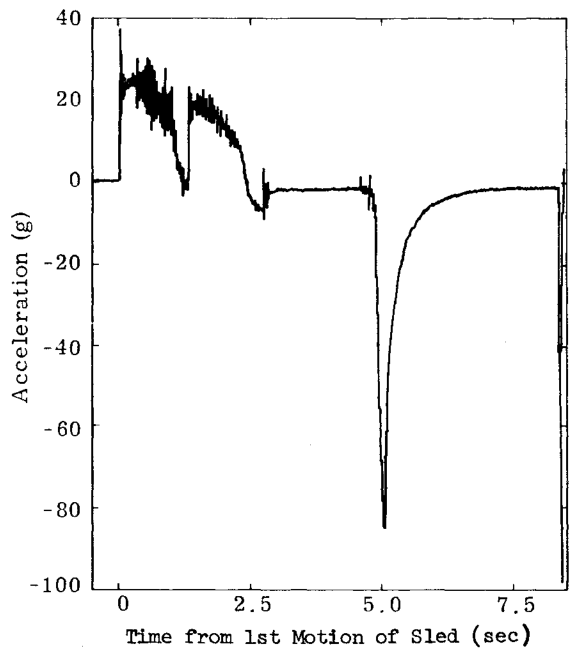


Fig. 6 Deceleration for all-nylon parachute on Test No. 7.

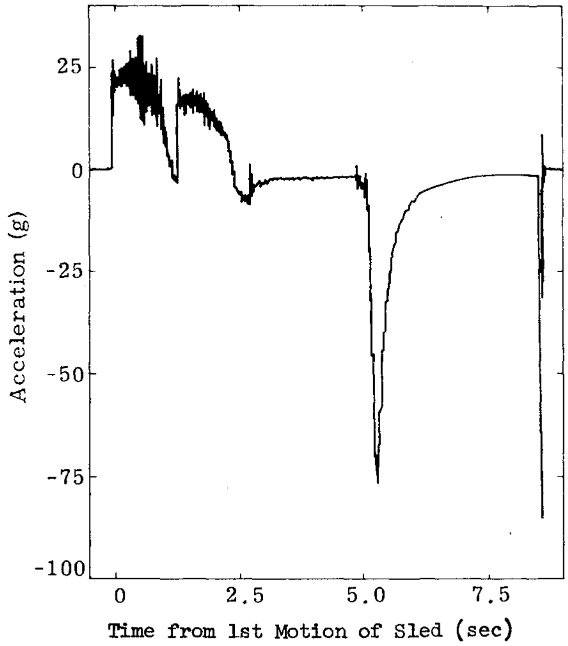


Fig. 7 Deceleration for nylon canopy/Kevlar-29 lines parachute on Test No. 8.

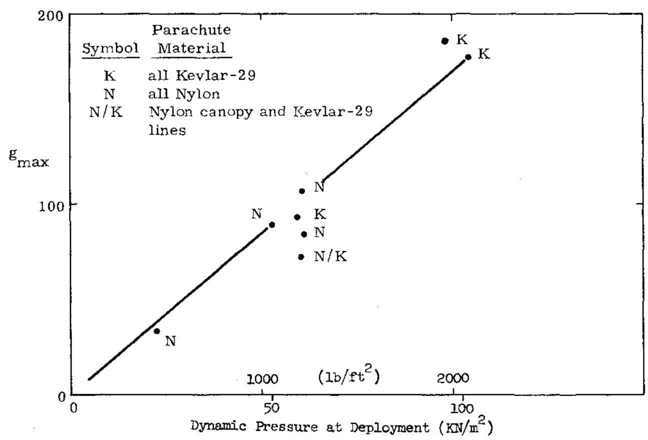


Fig. 8 Variation of peak deceleration with dynamic pressure at deployment for 3.81 m (12.5 ft) diam ribbon parachutes.

The variation of percent inflation with time for tests 5, 7, and 10 is shown in Fig. 9. Comparison of the three tests shown in Fig. 9 and the drag areas (column 13 of Table 1) show that the all-Kevlar, all-nylon and Kevlar lines with nylon canopy all have the same drag performance. The filling times as a function of dynamic pressure at deployment initiation are shown. The average drag area determined from the laser tracker trajectory data is listed in Table 1. There is a large fluctuation in these data which limits accuracy probably ±50%.

The first all-Kevlar-29 parachute tested (No. 3) resulted in only about 70% inflation [(C_DS = 4.2 m^2 (45 ft^2) compared with the normal 5.8 m^2 (63 ft^2)]. The partial inflation was due to "venetian blind"§ opening of the horizontal ribbons because of their low 4% ultimate elongation. In order to promote full inflation, three additional horizontal ribbons and one vertical per gore were added in constructing the next parachute, Serial No. G-2. When this parachute was tested (No. 5), approximately 20 of the 5.1 cm (2 in.) 13.3 kN (3000 lb) Kevlar ribbons (Nos. 1-7 as defined in Appendix A) nearest the vent were half torn, starting at the lower edge (nearest the skirt) of the ribbons. This was caused by the difference in circumference of the upper vs lower edge of the continuous ribbons and the low elongation causing greater loading of the lower edges. For parachute G-4, the original top 8 ribbons were replaced with a special vent band and 15 ribbons each 2.54 cm (1 in.) wide 8.9 kN/m^2 (2000 lb) Kevlar-29, to lessen the circumference difference and strengthen the crown area. Other minor changes are also described in Appendix A. This parachute (test 10) was deployed at a dynamic pressure of 1000 kN/m^2 (2080 lb/ft^2). Two gores failed from the skirt band up to the 8.9 kN, 2.54 cm wide ribbons. Analysis by S. D. Meyer indicates that this failure was due to a stress concentration at the interface region between the 8.9 kN, 2.54 cm (2000 lb, 1 in.) wide and 8.9 kN, 5.08 cm (2000 lb, 2 in.) wide ribbons. A new parachute was built with graduated fullness added to the six ribbons adjacent to the stress concentration area. This parachute was to be tested on No. 15 but an electrical short resulted in no deployment. This parachute (serial No. G-5) was recovered relatively undamaged and was repacked for test 17, where it was deployed at a dynamic pressure of 101 kN/m^2 (2109 lb/ft^2). Three gores were torn, one from the skirt band up to the 2000 lb, 1

§"Venetian blind" refers to the parachute ribbons in cross section being more open like a venetian window shade half open.

Table 1 Parachute sled test results

Test No.	Test date	Parachute type	Vehicle with chute, kg	Vehicle with chute, lb	Parachute weight, kg	Parachute weight, lb	Pack weight, kg	Pack weight, lb	Lid fire V_x, m/s	Lid fire V_x, ft/s	Lid fire V, m/s	Lid fire V, ft/s	Lid fire q, kN/m	Lid fire q, lb/ft^2	max g's	t_{fill}, s	Average ρ, g/m^3	Average ρ, slugs/ft^3	Average C_DS, m^2	Average C_DS, ft^2	t_i, s	γ_i, deg	V_i, m/s	V_i, ft/s	Range from launch to impact, m	Range from launch to impact, ft	Parachute serial No.	Results
1	1/31/75	Nylon	227	501	19.6	43.25	24	53	366	1200	...	...	...	...	...	...	1.0256	0.002	...	...	8.0	−3	305	1000	2400	7872	302813	Vehicle went free-flight, TM wire failed.
2	3/7/75	Nylon	230	506	19.5	43	24.9	55	370	1213	312	1023	49.3	1030	90	0.14	1.0087	0.001967	5.85	63	8.11	−5	104	340	2380	7810	302809	Chute deployed 0.7 s before impact. Successful. Chute half-filled.
3	4/8/75	Kevlar	221	487	9.0	19.9	11.8	26	368	1207	328	1076	54.5	1139	56	0.31	1.0313	0.002011	4.18	45	7.48	−20	40	131	1740	5708	G-1	Successful. Chute 70% filled.
4	7/10/75	Nylon	230	506	19.5	43	25.4	56	375	1230	340	1115	59.6	1244	...	...	0.9774	0.001906	...	...	7.48	−3	317	1040	2333	7654	302809	Vehicle went free-flight, wrong connector link used.
5	8/12/75	Kevlar	219	483	8.9	19.6	11.8	26	379	1244	343	1126	57.0	1190	95	0.246	0.9780	0.001907	5.85	63	7.80	−33	27	90	1674	5500	G-2	Successful.
6	8/27/75	Nylon	229	504	19.5	43	24.9	55	134	440	198	650	21.1	440	35	0.47	1.0790	0.002104	5.85	63	13.60	−41	23	75	1158	3800	302801	Deployed at low speed, 1st stage rockets did not all fire.
7	9/26/75	Nylon	229	503	19.5	43	24.9	55	372	1220	340	1115	58.4	1220	85	0.156	0.9733	0.001898	5.85	63	8.35	−34	24	80	1646	5400	302801	Successful.
8	10/16/75	Kevlar lines Nylon Canopy	222	490	12.6	27.8	16.8	37	366	1200	337	1106	57.5	1200	75	0.37	1.0082	0.001966	5.85	63	8.54	−41	21	69	1766	5794	G-3	Successful.
9	6/11/76	Nylon	240	530	19.5	43	26.7	58.8	375	1229	344	1130	57.5	1200	108	0.20	0.9610	0.001874	5.85	63	5.53	−29	20	65	923	3027	51789-1	Successful. Gage leads pulled loose.
10	6/22/76	All Kevlar 1-in. ribbons	217	479	10.0	22.12	12.7	28	510	1672	457	1500	99.6	2080	178	0.08	0.9431	0.001839	5.85	63	7.10	−60	23	75	1052	3450	G-4	Split 2 gores. Successful.
15	8/31/77	Same as above with fullness of ribbons	238	524	9.6	21.2	15.0	33	(518)	(1700)	(452)	(1484)	(107)	(2232)	...	...	...	...	...	...	...	...	...	...	...	...	G-5	Vehicle went free-flight. Electrical short.
17	6/2/78	Same as No. 15	225	497	9.6	21.2	15.0	33	516	1692	454	1490	100	2109	180	0.10	0.9744	0.001900	3.7	40	7.20	−45	27	90	1219	4000	G-5	Successful. 3 gore half split.

Notes: ... = no data; ( ) = desired value. Test numbers 11 thru 14 were for different programs.

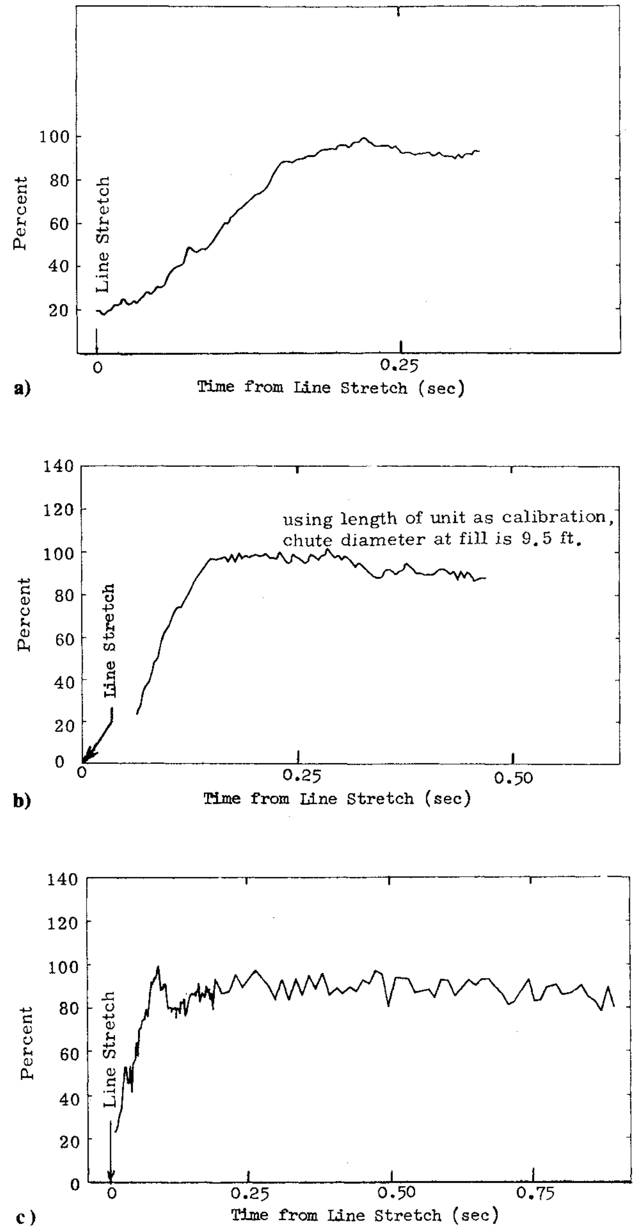


Fig. 9 Variation of percent of maximum inflated diameter with time from line stretch: a) all-Kevlar-29, Test No. 5; b) all-nylon, Test No. 7; and c) nylon canopy and Kevlar-29 lines, Test No. 10.

in. wide ribbons. Onboard movies indicate that the tearing started at the ribbons nearest the skirt band and progressed toward the vent. At the start of the ribbon failure, the parachute was approximately full open. The velocity was about 305 m/s (1000 ft/s) and the dynamic pressure 45.5 kN/m^2 (950 lb/ft^2). It is indicated that the ribbon fullness added during construction did eliminate ribbon tearing during the final dynamics of inflation. P. C. Klimas[8] made a calculation of the dynamic pressure differential over the canopy as it nears full inflation and showed a maximum pressure coefficient of 2.7 at 24% of the radial length from

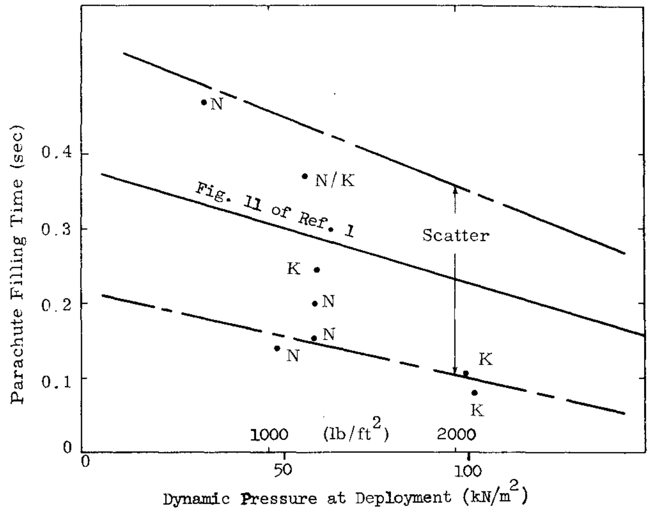


Fig. 10 Variation of filling time with dynamic pressure at deployment initiation for all 3.81 m (12.5 ft) diam parachutes.

the skirt. Using the formula in Ref. 1,

$$s = \Delta p \frac{\gamma\delta}{100}$$

$$s = 2.7(45.5)(0.61)(5.08/100) = 3.78 \text{ kN}(850 \text{ lb})$$

This explains the 4.45 kN (1000 lb) ribbon's failing, since normally a design factor of 2 is used for the ratio of calculated load to rated maximum load to allow for such factors as unsymmetrical loading, stitching losses at vertical seams, short ribbons, etc. Dynamic inflation calculations show that this failure mode could be eliminated by increasing the ribbon spacing 50% in the top third of the canopy to increase the filling time about 50%.

Conclusions

Nine 3.81 m (12.5 ft) diam ribbon parachutes were deployed in free-flight using a nominal 227 kg (500 lb) total-weight test vehicle. The parachutes were normally deployed at a dynamic pressure of approximately 57 kN/m^2 (1200 lb/ft^2) with one test at 21 kN/m^2 (440 lb/ft^2), one test at 100 kN/m^2 (2080 lb/ft^2), and one test at 101 kN/m^2 (2109 lb/ft^2). Comparison of data from all-nylon, all-Kevlar-29, and nylon canopy with Kevlar-29 suspension lines has led to the following conclusions:

1) Kevlar-29 material can be used successfully to replace nylon in parachute construction with an attendant 50% saving in weight and volume.

2) No discernible difference in maximum deceleration, filling time, or drag area was found in comparing the all-Kevlar-29 parachutes with the all-nylon parachutes.

3) The parachute design had to be altered when using Kevlar-29 to account for the low elongation (4–7%) of Kevlar-29.

4) The hybrid parachute with Kevlar-29 suspension lines and nylon canopy weighed 65% of the all-nylon parachute weight and produced only 75 g peak opening load as compared with about 94 g for the all-nylon parachute.

Appendix A

3.81 m (12.5 ft) diam ribbon parachute specifications

Diameter: 3.81 m (12.5 ft) across base of cone
Cone angle: 15 deg
Number of gores: 16
Vent diameter: 38.1 cm (15 in.)
Radials:
- Length: 199.6 cm (78.6 in.) with a tolerance of +5.08 cm (+2 in.) and −0.
- Strength: Double 4.45 kN (1000 lb) strength standard flat ribbon.

Verticals
- Quantity: Six per gore equally spaced.
- Strength: Double 2.22 kN (500 lb) tensile strength tape, 9/16 in. wide MIL 5038, Type V.

Ribbons
- Strength: Ribbon Nos. 1 (vent band) through 8: 13.3 kN (3000 lb) breaking strength standard flat.
  Ribbon Nos. 9 through 16: 8.9 kN (2000 lb) breaking strength standard flat.
  Ribbon Nos. 17 through 24 (skirt band): 4.45 kN (1000 lb) breaking strength standard flat.
- Spacing tolerance: Top 15 spaces: 2.29–2.54 cm (0.9–1.00 in.). Bottom 8 spaces: 3.05–3.30 cm (1.20–1.30 in.).
  All ribbons are continuous with one 15.24 cm (6 in.) long splice for each of the 24 ribbons located 90 deg apart such that ribbon No. 1 is in gore 1, ribbon No. 2 splice is in gore 5, etc.

Suspension lines (continuous over canopy):
- Strength: 40 kN (9000 lb) tensile strength Type XX.
- Length: 14 ft from skirt to end of loop.
- Vent lines: Are continuation of suspension lines and should be sewed in 10% less than vent diam. Suspension lines 1, 7, 9, and 10 are to be made from one continuous piece of webbing. Lines 5, 6, 13, and 14; lines 3, 4, 11, and 12; and lines 7, 8, 15, and 16 are to be made the same way. There is one splice for every four suspension lines. Splices are made on the radial with the skirt end of the splice in lines 5 and 16 located 6.4 cm (21 in.) above the skirt band, and the skirt end of splice in lines 2 and 11 located 12.8 cm (42 in.) above the skirt band.
- Suspension line skirt attachment
  Install 26.7 (6000 lb) tensile strength "Y" gusset as per detail B of Sandia drawing, SK60(5144)26950, Issue B. Lengths of the gussets to be such that, with a 44.5 N (10 lb) pull on the suspension line perpendicular to the skirt, the top edges of the gussets are tight.
- Pocket bands
  Install at intersection of 16 suspension lines with skirt band using 16 kN (3600 lb) tensile strength webbing Type VIII. Install as shown in Sandia drawing SK60(5144)26950.

Change to Parachute Serial No. G-4

3.81 m (12.5 ft) diameter ribbon parachutes made entirely of Kevlar-29 manufactured per MIL-P-38019A (USAF) Amendment 2, dated May 23, 1975.

Incorporate the following changes to above MIL specification:
1) Make suspension line length 5.03 m (16.5 ft) from skirt band to end of line loops.
2) Form vent band (which is ribbon No. 1) by using two each 40 kN (9000 lb) 2.54 cm (1 in.) wide webbing side-by-side.
3) Vent diam (inner edge), 35.5 cm (14 in.) (along construction cone).
4) Vent line length, 31.75 cm (12.5 in.) (measured dimension).
5) Ribbon Nos. 2 through 15 to be 8.9 kN (2000 lb), 2.54 cm (1 in.) with 0.84 cm (0.33 in.) spacing.
6) Ribbon Nos. 16 through 25 to be 8.9 kN (2000 lb), 5.08 cm (2 in.) wide with 1.67 cm (0.66 in.) spacing.
7) Ribbon Nos. 26 through 34 (skirt band) to be 4.45 kN (1000 lb) 5.08 cm (2 in.) wide with 2.39 cm (0.94 in.) spacing.
8) Use heavy grade 0.165 cm (0.065 in.) thick buffers on suspension lines centered 1.22 m (4 ft) from end of line loops.
9) Chute will have 7 verticals per gore.

Appendix B

Comparison of Kevlar-29 webbings with nylon webbings used for the 3.81 m (12.5 ft) diam ribbon parachutes

Component	Nylon version				Kevlar version			
	Strength		Width		Strength		Width	
	kN	lb	cm	in.	kN	lb	cm	in.
1 Horizontal	13.3	3,000	5.08	2	13.3	3,000	5.08	2
2 Horizontal	8.9	2,000	5.08	2	8.9	2,000	5.08	2
3 Horizontal	4.45	1,000	5.08	2	4.45	1,000	5.08	2
4 Vertical	2.22	500	1.43	9/16	2.22	500	1.27	½
5 Radial	4.45	1,000	5.08	2	4.45	1,000	5.08	2
6 Vent band	44.5	10,000	4.44	1¾	40	9,000	4.44	1¾
7 Skirt band	44.5	10,000	4.44	1¾	40	9,000	4.44	1¾
8 Suspension line	40	9,000	2.54	1	40	9,000	2.54	1
9 Loop	17.8	4,000	2.54	1	40	9,000	2.54	1
10 Reinforcement	26.7	6,000	2.54	1	40	9,000	2.54	1
11 Pocket band	16.0	3,600	4.44	1¾	40	9,000	4.44	1¾
12 Gusset	4.45	1,000	5.08	2	4.45	1,000	5.08	2
13 Loop	17.8	4,000	2.54	1	40	9,000	2.54	1
14 Loop	17.8	4,000	2.54	1	40	9,000	2.54	1
15 Keeper	4.45	1,000	2.54	1	...	None		...
16 Sleeve, buffer			Leather, KK-L-169, TY I, CL 1		Leather, KK-L-169, TY I, CL 1			

Basic Material Strengths

Material description	Width		Spec. max.		Kevlar		Actual strength No. 1		No. 2		No. 3		Average		Requested minimum strength	
	cm	in.	g/m	oz/yd	g/m	oz/yd	kN	lb	kN	lb	kN	lb	kN	lb	kN	lb
Ribbon	5.08	2	13	0.5	5.2	0.2	5.61	1262	5.83	1310	6.16	1384	5.87	1319 (5)[a]	4.45	1000
Ribbon	5.08	2	26	1.0	9.1	0.36	13.70	3080	12.94	2910	13.83	3110	13.49	3033 (5)	8.9	2000
Ribbon	5.08	2	31	1.2	12.4	0.48	18.90	4250	18.68	4200	15.61	3510	17.73	3987 (5.5)	13.3	3000
Webbing	2.54	1	84.3	3.25	35.5	1.37	43.01	9670	39.63	8910	43.10	9690	41.92	9423 (7)	40	9000
Webbing	4.44	1¾	90.8	3.5	34.8	1.34	42.12	9470	42.61	9580	38.25	8600	41.00	9217 (7.5)	40	9000
Tape	1.27	½	5.19	0.2	2.07	0.08	3.16	711	3.16	711	2.95	664	3.09	695 (5)	2.22	500

[a] Elongation (%)

Material	Construction
4.45 kN Kevlar ribbon, 5.08 cm wide (1000 lb Kevlar ribbon, 2 in. wide)	Woven similar to MIL-T-5608, Type II, Class D
8.9 kN Kevlar ribbon, 5.08 cm wide (2000 lb Kevlar ribbon, 2 in. wide)	Woven similar to MIL-T-5608, Type II, Class E
13.3 kN Kevlar ribbon, 5.08 cm wide (3000 lb Kevlar ribbon, 2 in. wide)	Woven similar to MIL-T-5608, Type III, Class E
2.22 kN Kevlar tape, 1.27 cm wide (500 lb Kevlar tape, 0.5 in. wide)	Woven similar to MIL-T-5038, Type III
40 kN Kevlar webbing, 2.54 cm wide (9000 lb Kevlar webbing, 1 in. wide)	Woven similar to MIL-W-4088, Type XXV except 1500 denier yarn
40 kN Kevlar webbing, 4.44 cm wide (9000 lb Kevlar webbing, 1¾ in. wide)	Woven similar to MIL-W-4088, Type XVI except 1500 denier yarn

Sewing threads

Construction	Twist Ply(s)	Cable (Z)	Tensile strength kN	lb
200/2/3	6.5	7	0.3	67.3
200/2/2	6.5	7	0.2	46.2
200/3	6.5	7	0.15	33.1
200/1	6.5	...	0.05	10.4
1500/2	2.0	5	0.64	145.0

Seam description	Strength No. 1 kN	lb	No. 2 kN	lb	No. 3 kN	lb	Average kN	lb	Seam efficiency, %
Susp. line/skirt	39.92	8975	39.95	8980	40.61	9130	40.16	9028	96
Susp. line splice	36.65	8240	34.47	7750	35.25	7700	35.13	7897	84
Skirt band splice	35.41	7980	37.19	8360	36.43	8190	36.34	8170	88.9
Horiz. ribbon splice 4.45 kN (1000 lb)	14.59	3280	14.63	3290	14.72	3310	14.65	3293	82.9
Horiz. ribbon splice 8.9 kN (2000 lb)	11.16	2510	10.85	2440	12.01	2700	11.34	2550	84
Horiz. ribbon splice 13.3 kN (3000 lb)	5.38	1210	5.60	1260	5.43	1220	5.47	1230	93.5

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References

[1] Pepper, William B. and Maydew, Randall C., "Aerodynamic Decelerators—An Engineering Review," *Journal of Aircraft*, Vol. 8, Jan. 1971.

[2] Coskren, R.J., Abbot, J., and Ross, J.H., "Kevlar-29 Parachute Fabrics," Paper 75-1360, AIAA 5th Aerodynamic Deceleration Systems Conference, Albuquerque, N. Mex., Nov. 17-19, 1975.

[3] Williams, Dale, "Investigation of Fiber B as a Lightweight Parachute Recovery System Material," Goodyear Aerospace Corp., Akron, Ohio, GER-16012, April 1974.

[4] "Comparison of Parachute Performance at Transonic Mach Numbers for Conical Ribbon Parachutes Constructed of Nylon and Kevlar-29 Materials," AEDC-TR-76-21, Feb. 1976.

[5] Pepper, William B., "Test Results Relevant to the Selection of the 12.5-Foot Diameter Ribbon Parachute," Sandia Laboratories, Albuquerque, N. Mex., SC-DR-64-18, April 1964.

[6] Kampfe, W.R., "SLAP/TV-Low 'Q' Sled Tests," SLA R-474201-206, March 31, 1976.

[7] Schelby, F. and Water, P.L., "Transducer Development for Sled Launched Adaptive Parachute Program (SLAP-TV)," SLA 74-0050, Feb. 1974.

[8] Meyer, S.D., Klimas, P.C., and Wolf, D.F., "Structural Analysis and Design of a High Performance Lifting Ribbon Parachute," AIAA Paper 79-0428, AIAA 6th Aerodynamic Decelerator and Balloon Technology Conference, Houston, Texas, March 5-7, 1979.