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Design and Development of the 24-Ft Diam Hybrid Kevlar-29/Nylon Ribbon Parachute

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A total of 70 tests, including static tests, rocket sled launchings, and rocket-boosted and aircraft drops, have been used to develop the 24-ft diam. hybrid Kevlar-29/nylon ribbon parachute for recovery of the 760-lb store. The parachute has been deployed successfully over an environmental temperature range of −65° to 160°F and has operated successfully over the design range of deployment speeds from 330 KCAS to Mach 1.2 at sea level.

Nomenclature

C_D	= parachute drag coefficient based on S
D	= parachute constructed diameter, m
g_{max}	= maximum deceleration, g's
h	= altitude, m
L	= reefing line length, m
M	= Mach number
q	= dynamic pressure = $1/2\rho V^2$ (kN/m^2)
R	= reefing ratio = $100(C_DS_r/C_DS)$, %
S	= parachute constructed area = $\pi/4D^2$, m^2
t	= time, s
V	= vehicle velocity, m/s
W_T	= weight of test vehicle and parachute system, kg
Δ	= incremented value
λ_G	= geometric porosity of canopy, %
ρ	= air density, kg/m^3

Subscripts

D	= gas generator fire
d	= deployment time from gas generator fire to line stretch
f	= canopy filling time from line stretch to full open
i	= impact
r	= reefed parachute

Introduction

NYLON has been used successfully for the construction of high performance parachutes[1] since World War II. Recently a new synthetic fiber called Kevlar-29[2] has been introduced by DuPont. This new material has a fiber tensile strength of over 2.8×10^6 kN/m^2 (400,000 psi), as compared to about 6.9×10^5 kN/m^2 (100,000 psi) for nylon. Wind tunnel tests[3] of 1.95-m (6.4-ft) diam. ribbon parachutes indicated that a 52% weight savings could be effected by using Kevlar-29 instead of nylon, with no attendant increase in deployment loads. Higher loads had been anticipated because of the low ultimate elongation (about 5%) for Kevlar-29, compared to 25% for nylon. Exploratory free-flight deployment tests conducted by the author[4] using 3.8-m (12.5-ft) diam ribbon parachutes showed that Kevlar-29 could reduce weight and volume by 50% compared to nylon.

For these reasons Kevlar-29 was the basis for a new 7.3-m (24-ft) diam hybrid ribbon parachute† design for a 345-kg (760-lb) store. This report describes the results of three static tests, 28 rocket sled launched free-flight tests, 31 aircraft drop tests, and 11 rocket-boosted overtests of the parachute.

Parachute Design

The 7.3-m (24-ft) diam hybrid Kevlar-29/nylon ribbon parachute‡ has 24 gores and 24 suspension lines. Gore construction is shown in Fig. 1. The design is 20-deg conical and is called "hybrid" because some ribbons are nylon. There are fifty-four 50.8-m (2-in.) wide continuous horizontal ribbons and seven verticals per gore made of double 2.4 kN (550-lb), 27-mm (1/2-in.) wide, Kevlar-29 tape.

The top 21 ribbons (No. 1 is at the vent band) were 13.3-kN (3000-lb) reinforced selvage nylon. Nylon was used because the differential circumference between the upper and lower edge of each continuous ribbon could cause stress concentration and failure of the low elongation Kevlar-29. Smaller width 1-in. Kevlar-29 ribbons could have been used for the upper ribbons, as was done in Ref. 4, but the weight saving would be small because of the short length of these top ribbons. Using nylon was the more conservative approach. Ribbons 22 through 31 were made of 8.9-kN (2000-lb) Kevlar-29. Graduated fullness was added to ribbon 22 by making it 4% longer than normal. This fullness was graduated linearly to zero for ribbon 29. The fullness was added to prevent stress concentration between ribbons 21 and 22 in going from 13.3-kN (3000-lb) nylon to 8.9-kN (2000-lb) Kevlar-29. Ribbons 32 through 54 (skirt band) were 4.5-kN (1000-lb) Kevlar-29. The vent band was made of 44.5-kN (10,000-lb) nylon, 44.4-mm (1¾-in.) wide, and the skirt band was made of 66.7-kN (15,000-lb) Kevlar-29, 44.4-mm (1¾-in.) wide. The suspension lines were made of 60-kN (13,500-lb), 2.86-cm (1⅛-in.) wide, Kevlar-29. The lines were constructed over the canopy with the "figure 8" construction, i.e., one splice for four suspension lines. The lines were 8.5-m (28-ft) long from suspension line lug loop to skirt band. A 28-ft long reefing line was used for a high altitude option (46% reefing) to limit time of fall, but not for maximum drag load control. The fabric portion of the parachute, bag, and reefing system weighed 40.8 kg (90 lb) and was packed to a high density of 688.8 kg/m^3 (43 lb/ft^3) in a pack volume of 0.0592 m^3 (2.1 ft^3). The parachute is shown packed in Fig. 2 and deployed in Fig. 3.

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†This hybrid parachute may have great potential for use as a decelerator or spin recovery parachute for fighter aircraft or bomber aircraft where weight and/or volume are critical. Further testing under sustained loads approaching an infinite mass condition would be needed.

‡All development parachutes were manufactured by Pioneer Parachute Company, Inc., Manchester, Conn.

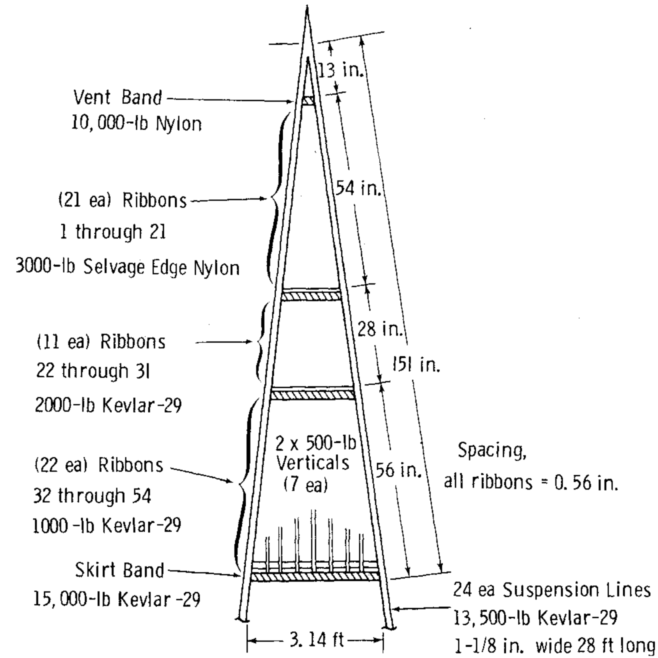

Fig. 1 Diagram of 24-ft ribbon parachute.

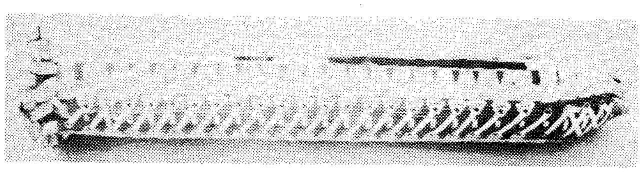

Fig. 2 Packed 24-ft parachute.

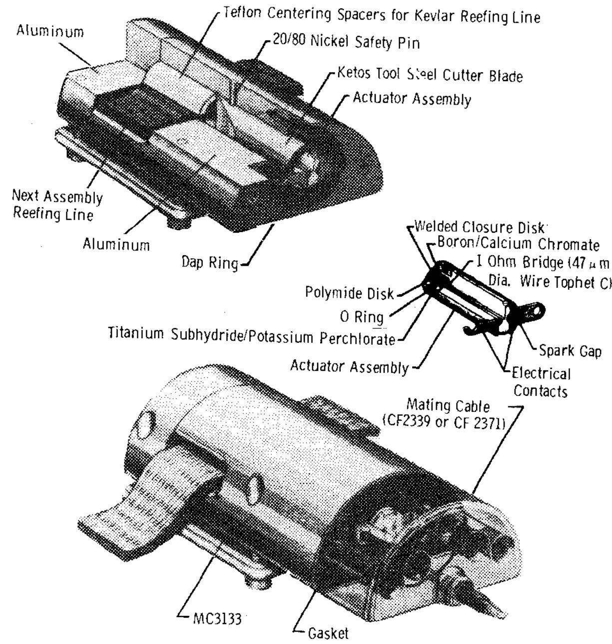

Fig. 4 MC3133 reefing line cutter.

Reefing System

A reefing system was installed in the parachute at the skirt band to limit down time from moderate altitudes of 25,000 ft. Two reefing cutters (Fig. 4) were mounted 180 deg apart at the skirt band. The MC 3133 cutter is fired instantaneously by an electrical cable soon after release from the aircraft. The firing cables are severed by cut knives at parachute deployment. For low level delivery, the cutters are fired severing the 28-ft long 13,500-lb tensile strength reefing line so the parachute opens

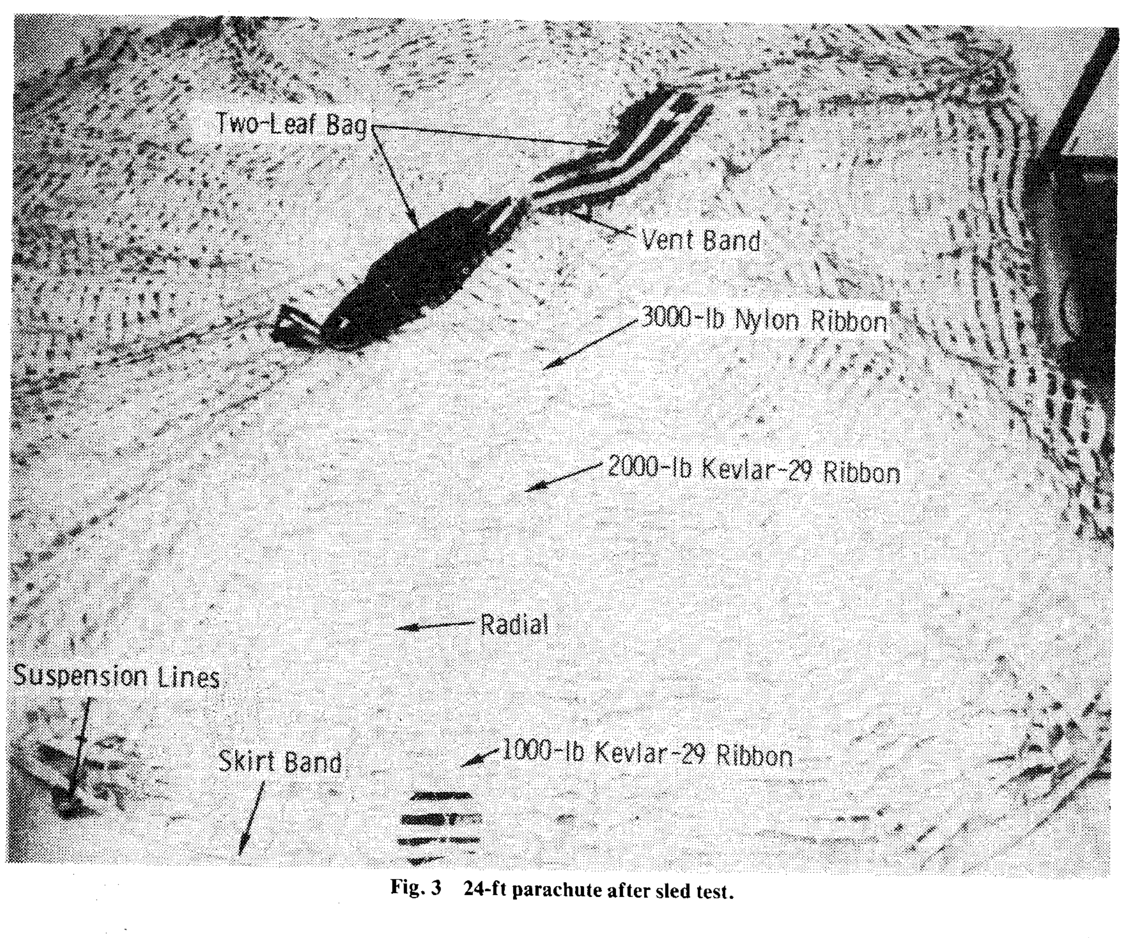

Fig. 3 24-ft parachute after sled test.

Table 1 Summary of sled test data

Test no.	Test temperature, °F	t_D,[a] s	V_D, ft/s	q_{D_2}, lb/ft^2	Δt_d, s	Δt_f, s	V_i, ft/s	g_{max}, g's	ρ, slugs/ft^3	Comments
1	amb.	2.576	1174	1310	0.24	0.76	58	60	0.001900	Successful
2		1.508	1515	2122	0.21	0.55	50	115	0.001880	
3		~1.57	~930	~850	0.16	0.64	52.5	...	0.001972	
4		1.5+	626	393	0.24	0.87	65.6	26.25	0.002008	
5		1.5+	615	373	0.38	0.35	50	38	0.001973	
6		1.44	1460	2135	0.27	0.28	55	164	0.002003	
7		~1.77	610	364	0.35	0.83	93	20	0.001956	
8		~1.57	...	~2660	...	...	...	...	...	Went free-flight, pull-out wire failed
9		1.06	1427	2060	0.17	0.28	...	180	0.002024	Successful
10		2.0	1164	1279	...	~0.5	...	77	0.001888	
11		~1.7	~680	~443	0.29	0.8	73	26	0.001915	
12	+160	1.7	1420	1880	0.215	0.38	52	133	0.001865	
13	amb.	1.5	1490	2076	0.25	0.36	54	151	0.00187	
14	amb.	2.2	1500	2104	0.24	1.42	80	47	0.00187	Suspension lines twisted due to vehicle roll
15	−65	1.5	630	370	...	...	53	65	0.001865	Successful
16	−65	2.217	1480	1944	0.15	0.27	55	161	0.001775	Successful
17	160	(2.2)	(1500)	(2148)	...	...	...	...	...	No gas generator fire
18	amb.	2.19	(670)	(430)	0.21	0.44	61	50	0.001955	Successful
19	160	3.0	670	441	0.24	0.63	70	35	0.001966	Successful
20	amb.	2.0	670	449	0.19	0.43	61	38	0.00200	Successful
21	amb.	2.19	580	328	...	...	70	28	0.00195	One Zuni rocket didn't fire, missed pad, short
22	−65	2.24	670	433	0.28	0.51	70	36	0.001928	Successful
23	−65	(2.19)	(670)	(430)	0.34	0.51	55	40	0.001928	One cutter didn't cut completely, missed pad to side
24	amb.	1.5	1490	2093	0.23	0.30	50	...	0.001886	
25	amb.	1.46	630	375	0.19	0.53	50	55	0.001889	Successful
26	−65	(1.5)	630	372	0.30	0.34	...	49	0.001872	Failed 13, 5, 5 + ribbons
27	+160	(1.5)	1480	2086	0.29	0.42	54	136	0.001905	Failed 23, 7 ribbons
28	−65	1.5	1470	2149	0.26	...	50	180	0.001989	Successful

[a] Time from upward ejection

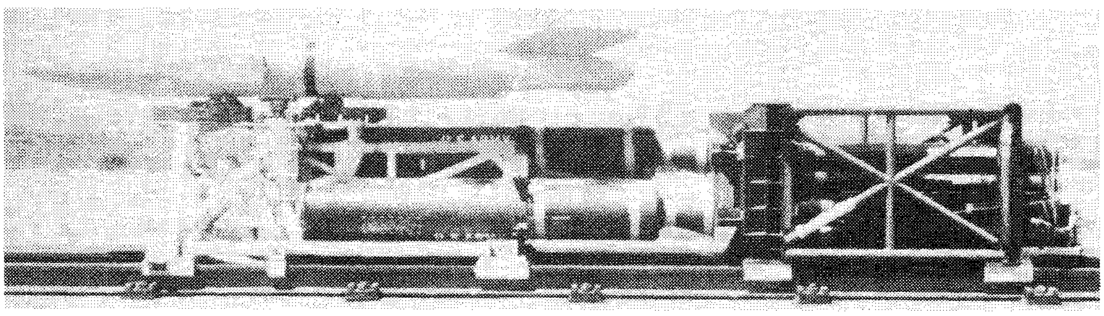

Fig. 5 Sled launched parachute test vehicle.

fully. Since the cutter does not have an explosive time delay, the shelf life is believed to be 25 years.

Deployment Method

A telescoping tube mounted along the centerline of the parachute pack powered by an MC 3002 gas generator is used to eject the parachute pack aft from the vehicle at a relative velocity of 165 ft/s. The gas generator can be fired at 0.30, 0.60, or 1.5 s after release, depending on the type of carrier aircraft.

Packing

Pressure packing with 26 tons on a hydraulic press along with a hydraulic bag lacing puller was used to achieve a high pack density of 43 lb/ft^3. The finished pack (Fig. 2) is 9.125 in. in diameter and 51 in. in length. The parachute, bag, and reefing system weigh approximately 90 lb, which is the same as a 17-ft diam all nylon parachute used in the same vehicle. The finished pack, including telescoping deployment tubes and load ring, weighs 115 lb.

To prevent movement of the pack during ejection from the vehicle, 1500-lb nylon retainer loops are used at the canopy skirt location and forward of the suspension line compartment. The retainers are cut by static cut knives during deployment.

Static Tests

Three static deployment tests were conducted to demonstrate proper and complete deployment of the parachute by the gas generator-powered telescoping tube. All tests were successful. Average velocity during line deployment was 140 ft/s on the first static tests. On the second test, initial tail can velocity was 200 ft/s with the average velocity during line deployment being 190 ft/s. Total deployment time was 0.28 s.

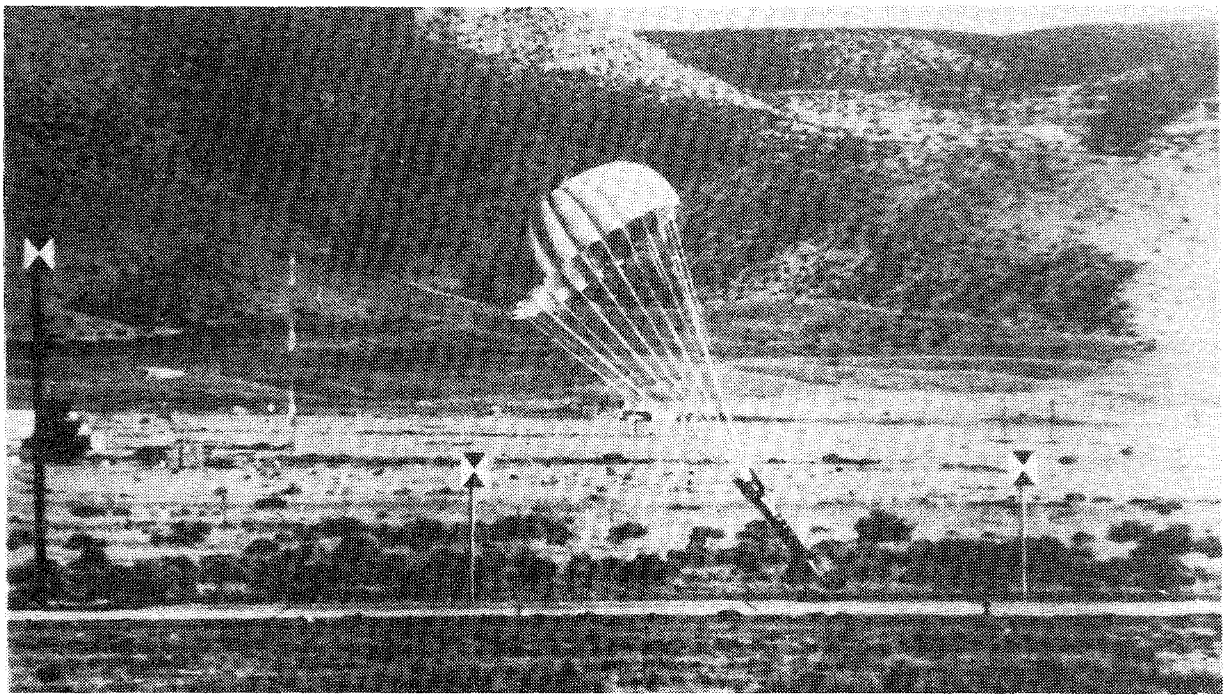

Fig. 6 24-ft diam hybrid Kevlar-29/nylon ribbon parachute near impact on concrete pad.

Table 2 Aircraft drop test data

Test no.	V_0, ft/s	h_0, ft MSL	t_D, s	V_D, ft/s	M_D	q_D, lb/ft^2	Δt_d, s	Δt_f, s	C_D ft^2	t_i, s	V_i ft/s	g_{max} TM, g's	ρ_0, slugs/ft
1	830	13430	0.68	831	0.77	545	0.23	0.29	130	102.3	77	~45	0.00197
2	633	6369	0.59	640	0.57	382	0.36	0.25	130	15.21	75	43	0.00193
3	635	6358	0.62	641	0.57	383	0.30	0.37	270	19.62	51	39.8	0.00193
4	822	6420	0.60	824	0.74	645	0.26	0.27	120	15.64	82	ND	0.00191
5	856	6312	0.63	851	0.76	688	0.28	0.39	296	20.85	53	62	0.00191
6	1204	6619	0.59	1192	1.05	1302	0.21	0.32	140	18.30	75	ND	0.00184
7	1176	6470	0.62	1165	1.03	1250	0.20	0.40	265	21.39	54	95	0.00184
8	1257	5452	0.66	1200	1.08	1408	0.26	0.37	265	4.87	49	108	0.00185
9	613	1290	0.57	607	0.51	397	0.30	0.58	120	16.3	76	30	0.00211
10	604	1170	0.57	603	0.51	386	0.30	0.39	265	22.5	47	30	0.00212
11	1674	24561	0.67	1674	1.64	1522	0.22	0.20	130	220.67	80	160	0.00109
12	1500	8363	0.72	1470	1.34	1961	0.31	0.39	265	54.3	51	115	0.001813
13	652	7258	0.71	644	0.6	402	0.19	0.41	135	40.58	75	37	0.001966
14	1285	5435	0.43	1239	1.14	1612	0.42	0.41	265	3.65	65	100	0.002009
15	441	11874	35.39	711	0.64	494	0.29	0.41	130	44.03	77	33	0.001700
16	1398	5456	0.58	1376	1.24	1877	0.21	0.49	...	4.43	57	97	0.001991
17	1710	16530	0.68	1684	1.61	2034	0.21	0.21	130	137.4	78	185	0.001434
18	(1250)[a]	7225	24.61	1011	0.92	958	0.20	0.93	130	46.04	80	25	0.001881
19	704	15530	0.66	680	0.64	336	0.22	0.34	125	134.67	76	43	0.001475
20	1717	60475	16.27	1632	1.72	391	0.22	0.20	130	460.5	80	59	0.000228
21	629	6337	0.60	635	0.56	373	0.29	0.30	130	14.95	77	48.8	0.001859
22	629	6353	0.58	635	0.56	366	0.18	0.44	265	20.07	62	40.9	0.001856
23	849	6332	0.60	856	0.76	690	0.30	0.24	130	14.63	78	60	0.001903
24	875	6328	0.60	876	0.78	727	0.28	0.52	265	19.44	55	51	0.001903
25	618	5393	0.40	619	0.55	366	0.24	0.40	265	2.12	75	45	0.001106
26	757	22536	0.59	755	0.69	314	0.27	0.28	122	199.1	78	54	0.001106
27	756	22556	0.59	752	0.69	312	0.29	0.32	122	197.0	78	38	0.001106
28	1450	5435	(0.60)	(1430)	1.32	...	...	...	...	...	...	...	...
29	1441	5428	0.69	1418	1.29	2050	0.19	0.52	...	3.63	78	98	0.002047
30	2135	50358	56.23	1620	1.50	2540	0.21	0.36	130	75.0	78	139	0.000378
31	1162	6447	0.64	1161	1.06	1326	0.22	0.25	130	16.04	75	90	0.001975

( ) = Desired value

Sled Tests

Twenty-eight sled tests were conducted on the one-mile-long sled track in Area III at Sandia Laboratories, Albuquerque. Test parameters are listed in Table 1. The two-stage sled and test vehicle are shown in Fig. 5. Ten of these tests were used to develop and prove the new parachute design, and the other 18 were used to prove the vehicle electrical system and structural integrity of the case during slapdown (Fig. 6) on a concrete pad.

Drop Tests

Thirty-one aircraft drop tests of the 24-ft diam hybrid parachute have been conducted. Pertinent data is listed in Table 2. Most of these tests were conducted at the Sandia

Table 3 Rocket boosted overtests

Test no.	Test date	L^a m	L^a ft	R %	W_T kg	W_T lb	h_D MSL m	h_D MSL ft	V_D m/s	V_D ft/s	M_D	q_D kN/m^2	q_D lb/ft^2	T_D s	Δt_d s	Δt_f s	C_DS m^2	C_DS ft^2	V_t m/s	V_t ft/s	g_{max} g's
1	2/15/77	8.5	28	0	347	765	2194	7195	518	1700	1.53	129	2700	13.40	0.24	0.38	24	260	17	56	20
2	2/17/77	8.5	28	0	349	770	2174	7131	523	1715	1.53	132	2750	13.42	0.21	...	...	...	41.5	136	13
3	4/12/77	8.5	28	0	340	750	1868	6128	509	1670	1.47	124	2600	14.44	0.22	0.35	24.6	265	16.8	55	22
4	4/14/77	8.5	28	0	341	751	1860	6100	507	1662	1.49	126	2640	14.35	0.25	0.34	24.6	265	16.8	55	18
5	6/30/77	8.5	28	46	345	760	2565	8412	549	1800	1.60	134	2800	12.84	0.17	...	...	...	83.8	275	17
6	8/11/77	8.5	28	46	340	750	2764	9067	534	1753	1.56	125	2609	12.73	0.24	0.22	12.1	130	24.4	80	24
7	6/6/78	8.5	28	0	350	771	2592	8505	528	1731	1.54	125	2606	12.24	0.19	...	23.2	250	16.8	55	20
8	11/15/78	8.5	28	0	351	773	2855	9366	520	1706	1.58	129	2685	12.15	0.22	0.27	22.0	237	17.4	57	19
9	11/17/78	8.5	28	0	352	777	2791	9157	518	1700	1.58	129	2700	12.37	0.18	0.45	24.2	261	16.8	55	17
10	12/8/78	8.5	28	0	347	766	2652	8700	512	1680	1.57	129	2700	11.94	0.23	0.39	23.5	253	16.8	55	19
11	12/12/78	8.5	28	0	347	766	2605	8548	512	1681	1.55	127	2648	12.27	0.23	0.26	23.8	256	16.8	55	24

[a] Reefing lines were pre-cut for tests 1 through 4 and 7 through 11 and tests 5 and 6 were permanently reefed. Comments: Test no. 1 Successful; 2 Bad deployment, chute failed; 3 Successful; 4 Successful, some ribbon damage; 5 Bad deployment, chute failed; 6 Good reefed overtest; 7 Tore 26 ribbons; 8 Tore 31 ribbons; 9 Successful (8 ribbons torn); 10 Successful (11 ribbons torn); 11 Successful (one 1000-lb ribbon torn).

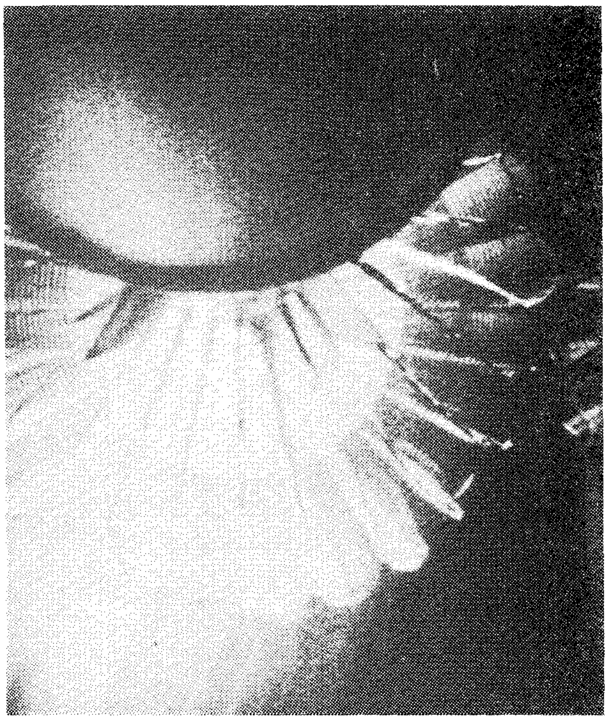

Fig. 7 Photograph from onboard camera of rocket-boosted overtest.

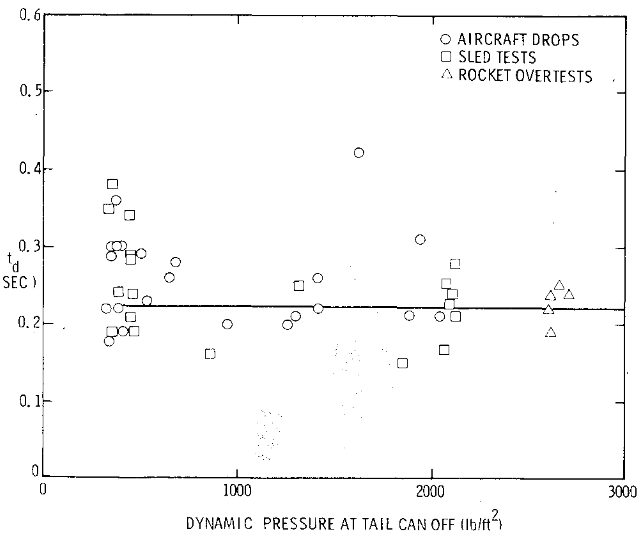

Fig. 8 Deployment time from tail can off to line stretch.

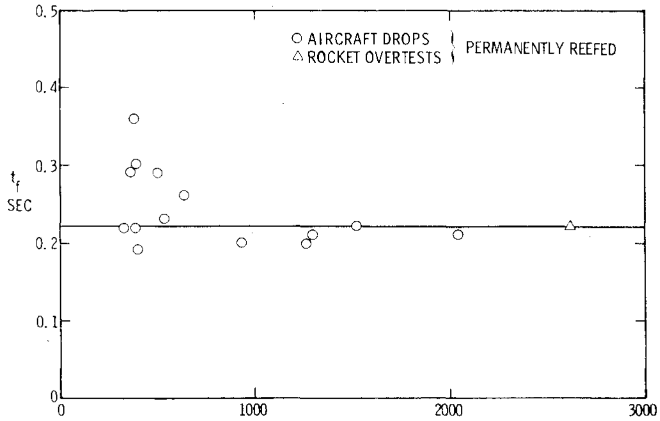

Fig. 9 Filling time from line stretch to open in the reefed condition.

Laboratory Tonopah Test Range, Nevada. A telemetry system was used to determine vehicle deceleration.

Rocket-Boosted Overtests

A specially designed test vehicle boosted by a Nike rocket was used to overtest the parachute at 125% of maximum design dynamic pressure. The vehicle weighed a nominal 345 kg (760 lb) and had a maximum diameter of 33.8 cm (13.3 in.). The vehicle was 3.6-m (141.84-in.) long. Two Photosonic cameras mounted in 180 deg opposing housings on the outer surface of the test vehicle were used to photograph parachute deployment at 200 and 500 frames per second. An eleven channel telemetry system in the test vehicle was used to measure deceleration, ram air pressure, and monitor functions. A Nike rocket with a burn time of about 3.4 s was launched at a 15-deg angle above the horizontal. Burnout was at about Mach 2.1 and a dynamic pressure of 258 kN/m^2 (5400 lb/ft^2). The vehicle coasted for 13 or 14 s from launch at which time the ram air pressure sensing switch fired a gas generator at a nominal dynamic pressure of 127.4 kN/m^2 (2660 lb/ft^2).

Test results are listed in Table 3. A photograph of the inflated parachute from an onboard camera is shown in Fig. 7.

Analysis of Data

Deployment and Filling Time

The most important parameter in determining parachute performance is the filling time. The deployment time (Fig. 8) from gas generator fire to line stretch and the parachute filling time (Figs. 9 and 10) from line stretch to fully open are shown as a function of dynamic pressure at gas generator fire.

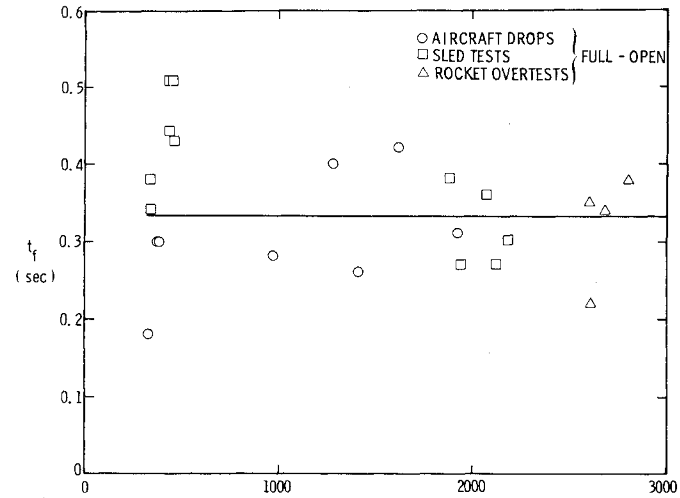

Fig. 10 Filling time from line stretch to full-open.

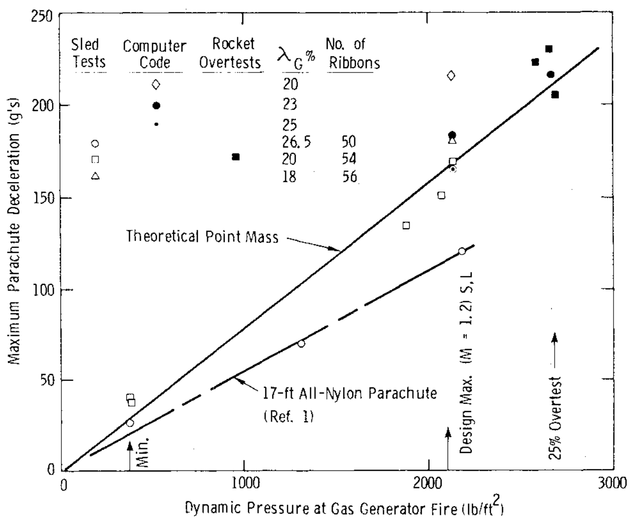

Fig. 11 Variation of maximum deceleration with dynamic pressure.

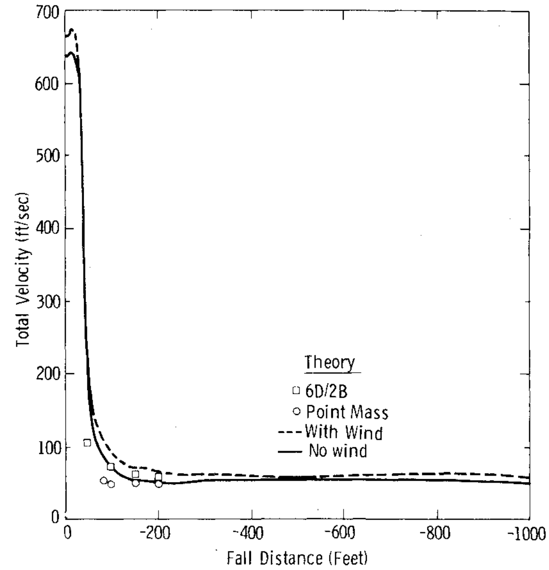

Fig. 12 Variation of velocity with fall distance for full-open 24-ft hybrid parachute.

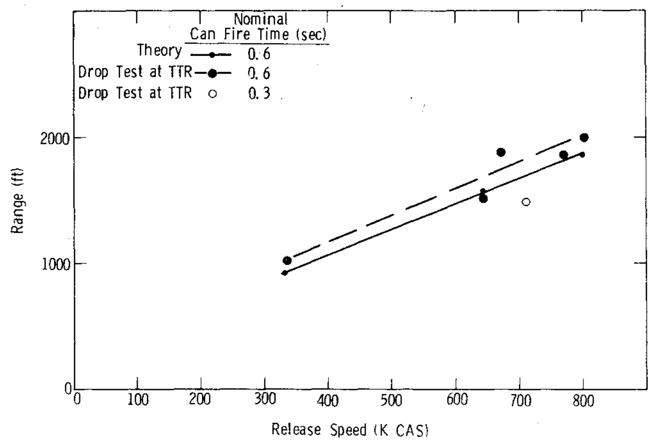

Fig. 13 Variation of range with release speed for 100 ft of fall.

Deployment time is relatively constant at 0.23 s over the dynamic pressure range. The filling time for the reefed parachute is constant at 0.21 s and 0.33 s for the full-open parachute over the dynamic pressure range. The constant filling time as compared to the variable filling time usually experienced with an all nylon canopy[1] is believed to be due to the low elongation of the Kevlar ribbons which results in less flow-through area between the Kevlar ribbons at low dynamic pressures.

Peak Opening Loads

The variation of maximum parachute deceleration with dynamic pressure at gas generator fire is shown in Fig. 11. The final design 54-ribbon data (open squares) compares well with the theoretical point mass trajectory values (solid line). Values for the initial 50-ribbon design (O symbol) are shown for reference. Maximum deceleration for the 50-ribbon design fall on data for the 17-ft all nylon parachute. The theoretical computer code for parachute filling with 25% geometric porosity (I symbol) agrees with the 54-ribbon test data, which had a 20% geometric porosity. It is believed that the low-elongation (5%) Kevlar ribbons "venetian blind" open during inflation, giving an effective porosity 5% greater than the geometric porosity. ("Venetian blind" refers to the cross-sectional view of the ribbons as compared to a venetian window shade partially open.) The peak deceleration of 240 g's measured on the rocket-boosted overtests (see Table 3) is the highest known, the previous standing record being 200 g's.[5] The peak deceleration at maximum design dynamic pressure of 2130 lb/ft^2 is 164 g's with an anticipated spread of ±10%. This is a force of 125,500 lb.

The maximum deceleration measured by telemetry during all aircraft drop tests is given in Table 2. Whether the parachute is permanently reefed to a drag area of 130 ft^2 or unreefed does not affect peak deceleration, since peak deceleration normally occurs when a parachute is about half open (50% CDS). Loads in the upper third of the canopy are the same for a reefed or unreefed parachute. Theoretical point mass trajectory values agree well with the experimental data for both reefed and unreefed chutes.

Velocity

The variation of total velocity with fall distance for Test R714151 is shown in Fig. 12 to illustrate typical optical data obtained from the parachute ballistic drop tests at TTR. Theoretical point mass trajectory values do not predict the measured values accurately until after 150 ft aft of fall. Values obtained by using the six degrees-of-freedom/two-body theoretical program are in good agreement with the solid curve (no wind).

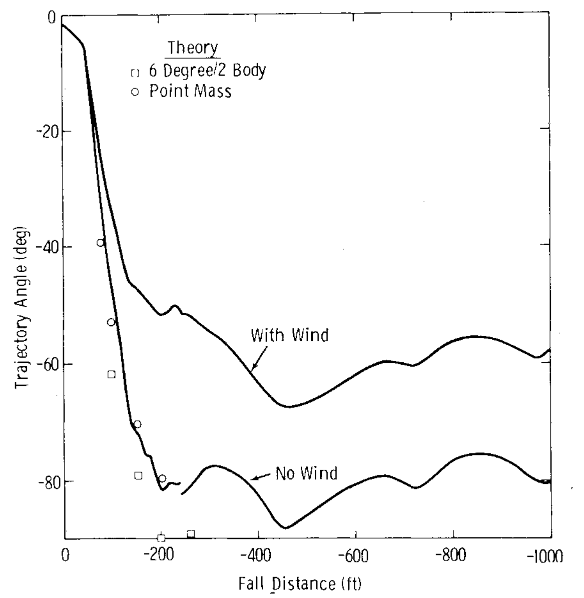

Fig. 14 Variation of trajectory angle with fall distance for drop test no. 3.

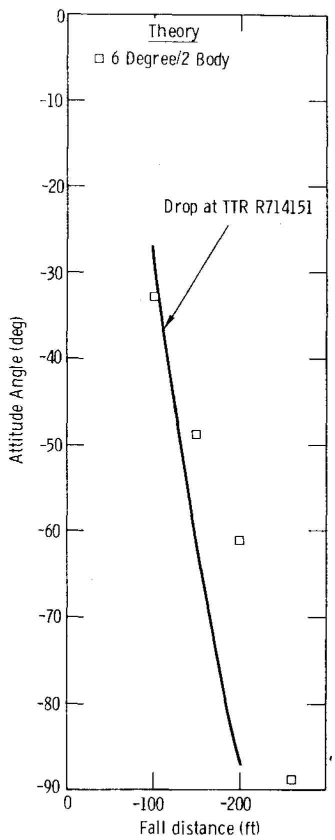

Fig. 15 Variation of attitude angle with fall distance for drop test no. 3.

Range

The variation of bomb range with release speed is shown in Fig. 13. Experimental data and theoretical point mass trajectory values agree reasonably well from 330 KCAS to 800 KCAS.

Trajectory Angle

The variation of trajectory angle with distance of fall for a typical parachute ballistic drop (R714151) is shown in Fig. 14. Theoretical point mass trajectory data agree well with the optical data (solid line). The theoretical six degrees-of-freedom/two-body values are about 10 deg too great for any selected fall distance. However, experimental data and the two theories are in reasonable agreement considering experimental scatter and modeling accuracy limitations.

Attitude Angle

The variation of the angle between the vehicle centerline and horizontal for a typical drop (R714151) at TTR is shown in Fig. 15. For the lowest delivery altitude anticipated for the vehicle, 100 ft above ground level, the attitude angle was -30 deg. At this time, the trajectory angle is -45 deg (from Fig. 14). The vehicle has a positive nose up angle-of-attack of 15 deg, which is predicted quite well by the six degrees-of-freedom/two-body theoretical trajectory. The attitude is vertical (90 deg) after about 200 ft of fall. The theory indicated 90 deg after 260 ft of fall, which is reasonable agreement considering variability expected with identical tests and uncertainty of input parameters.

Drag Area

The drag area of the full-open 24-ft diam hybrid parachute was measured in the NASA Ames 40 × 80-ft wind tunnel and was 265 ft^2. With a reference area of 452 ft^2, this is equivalent to a relatively high drag coefficient of 0.586, as would be expected with the low geometric porosity of 20%.

Table 4 Nominal drag area/time functions for the 24-ft parachute.

Full-open parachute	$\Delta t_{fire} = 0.6$				$\Delta t_{fire} = 0.30$	
Event	t,s	Δt_d,s	Δt_f,s	C_DS, ft^2	t,s	C_DS,ft^2
Release	0.00	...	...	0.30	0.00	0.30
Gas generator fire	0.6	0.26	...	0.30	0.30	0.30
Line stretch	0.86	...	0.38	0.30	0.56	0.30
Full-open	1.24	...	...	265.0	0.94	265.0
Impact	1000.0	...	...	265.0	1000.0	265.0
Permanently reefed						
Event	t,s	Δt_d,s	Δt_f,s	C_DS, ft^2		
Release	0.00	...	...	0.30		
Gas generator fire	0.60	0.26	...	0.30		
Line stretch	0.86	...	0.28	0.30		
Full-open	1.14	...	...	122.0		
Impact	1000.0	...	...	122.0		

Notes: 1. Use above values for all speeds (330 KCAS to $M = 1.2$) $W_T = 765$ lb. 2. For $\pm\sigma$ variation, vary Δt_{fire}, Δt_d, Δt_f, and C_DS by $\pm 10\%$.

The reefed parachute with 28-ft long reefing line had a drag area of 122 ft^2.

Nominal drag-area/time values for theoretical trajectory calculations are given in Table 4.

Conclusions

A 24-ft diam hybrid Kevlar-29/nylon ribbon parachute has been successfully developed. From three static deployments, 28 sled tests, 31 aircraft drops, and 11 rocket-boosted overtests the parachute has been qualified for the following extreme conditions:

1) Three successful overtests at 125% of maximum design dynamic pressure, i.e., 2660 lb/ft^2. One overtest was made in the permanently reefed condition.

2) Deployment at design maximum dynamic pressure 2130 lb/ft^2 (Mach 1.2 at SL) after soak at the maximum specification temperature of 160°F.

3) Deployment at the minimum design dynamic pressure (372 lb/ft^2, equivalent to 330 KCAS) after soak at the minimum specification temperature of −65°F.

4) Deployment in the permanently reefed condition at 750 KCAS at a release altitude of 23,700 ft above mean sea level.

5) Successful deployment at design maximum dynamic pressure of 2130 lb/ft^2 after exposure of the parachute pack to 90% relative humidity and 90°F for two months and then freezing the pack at −65°F for 24 h prior to sled test.

Acknowledgment

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References

[1] Pepper, W.B. and Maydew, R.C., "Aerodynamic Decelerators—An Engineering Review," *Journal of Aircraft*, Vol. 8, Jan. 1971, pp. 3-19.

[2] Coskren, R.J. and Abbott, N.J., "Kevlar-29 and 49 Parachute Fabrics," AIAA Paper 75-1360, presented at the 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, Report No. GER-16012, April 1974.

[4] Pepper, W.B., "Preliminary Evaluation of Kevlar-29 Versus Nylon by SLAP/TV Free-Flight Deployment Tests of 12.5-Ft Diameter Ribbon Parachutes," presented as Paper 79-0429 at the AIAA 6th Aerodynamic Deceleration and Balloon Technology Conference, Houston, Texas, March 1979.

[5] Pepper, W.B., "Recent Flight-Test Results in Deploying a 20-Ft-Diam Ribbon Parachute," *Journal of Aircraft*, Vol. 6, Jan.-Feb. 1969, pp. 74-76.