Overtest Results for the 7.3-m (24-ft) Diameter Hybrid Kevlar-29/Nylon Ribbon Parachute

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The design of a 7.3-m (24-ft) diameter hybrid Kevlar-29/nylon ribbon parachute is presented. The results of six Nike rocket-boosted overtests of the parachute are discussed. Four tests were successful with the parachute being deployed unreefed from the 345-kg (760-lb) test vehicle in free flight at a Mach number of about 1.5 and a dynamic pressure of about 125-kN/m² (2600 lb/ft²). A peak deceleration of 240 g's was measured. The use of Kevlar-29 in construction of the parachute has resulted in 2.25 times the drag area of a 5.2-m (17-ft) diameter all-nylon ribbon parachute with the same pack weight and volume.

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/m²
R = reefing ratio = $100(C_D S_r / C_D S)$, %
S = parachute constructed area = $(\pi/4)D^2$, m²
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/m³

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

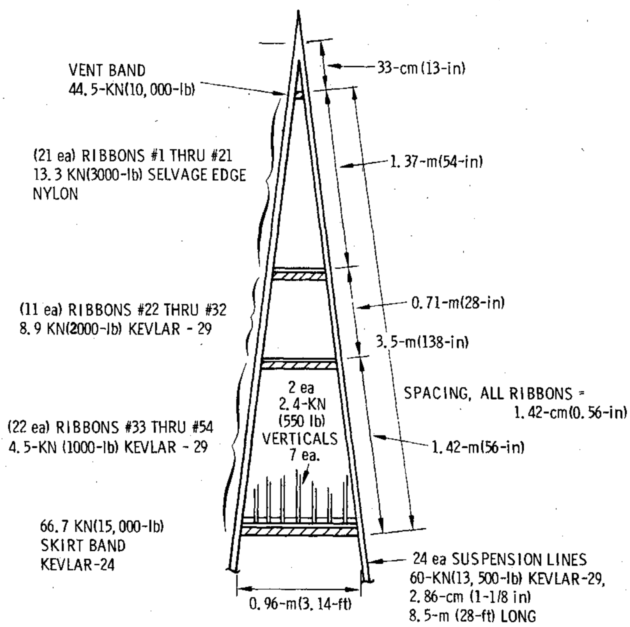

Fig. 1 Sketch of 7.3-m (24-ft) diam. ribbon parachute gore.

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] was introduced by DuPont. This new material has a fiber tensile strength of over 2.8×10^6 kN/m² (400,000 psi) as compared to about 6.9×10^5 kN/m² (100,000 psi) for nylon. Wind tunnel tests[3] of 1.95-m (6.4-ft) diameter ribbon parachutes indicated that a 52% weight saving 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) diameter ribbon parachutes made of Kevlar-29 and all-nylon parachutes substantiated that Kevlar-29 use could save 50% in weight and volume as compared to nylon.

For the preceding reasons Kevlar-29 was the basis for a new 7.3-m (24-ft) diameter hybrid ribbon parachute† design for a 345-kg (760-lb) store. This report describes the rocket-boosted overtests of this new parachute. The purpose of the overtests was to demonstrate deployment and inflation at a dynamic pressure 25% greater than design maximum.

Parachute Design

The 7.3-m (24-ft) diameter 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-mm (2-in.) wide continuous horizontal ribbons and seven verticals per gore made of double 2.4-kN (550-lb), 12.7-mm (½-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

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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 Parchute Co., Inc., Manchester, Conn.

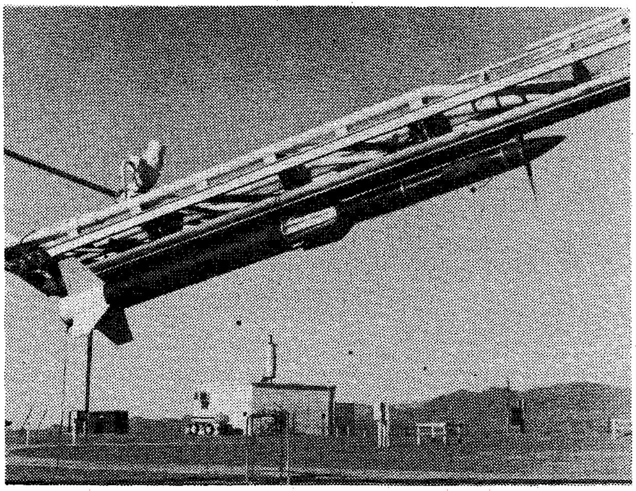

Fig. 2 Test vehicle on launcher.

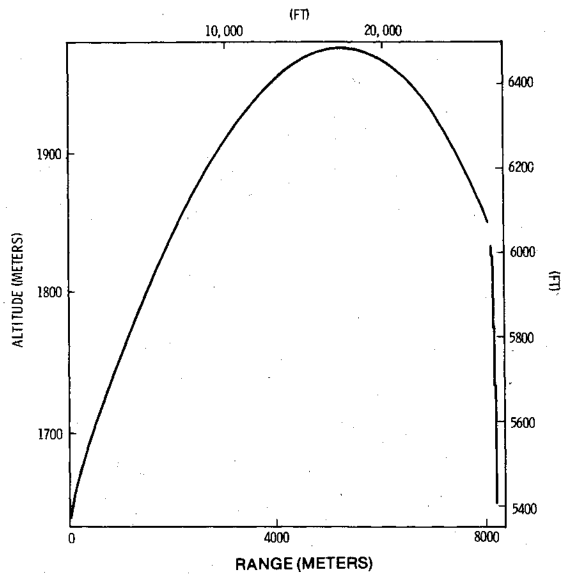

Fig. 3 Altitude vs range for test no. 3.

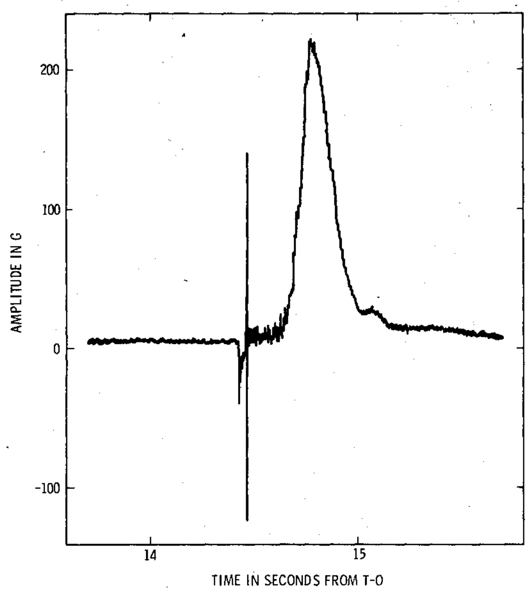

Fig. 4 Deceleration vs time from launch.

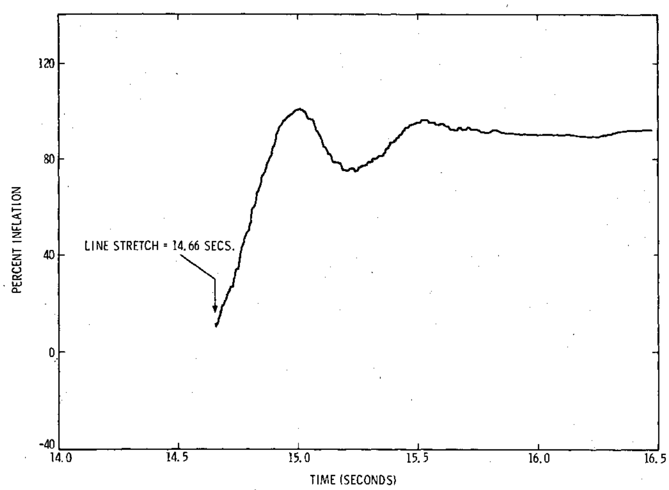

Fig. 5 Percent inflation vs time for test no. 3.

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. Ribbons 22-31 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 32-54 (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 continuous 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).

Apparatus

A specially designed test vehicle shown mounted on the launcher with the Nike rocket booster is shown in Fig. 2. 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 11-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 to 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). The gas generator powered a telescoping tube installed along the centerline of the parachute pack which deployed the parachute at a velocity of about 50.3 m/s (165 ft/s) relative to the vehicle. The tail can and deployment bag were permanently attached to the vent region of the parachute by four 40-kN (9,000-lb) nylon straps to prevent them from colliding with the canopy as it inflated and decelerated.

Rocket-Boosted Overtests

Six Nike rocket-boosted overtests of the 7.3-m (24-ft) diameter hybrid Kevlar-29/nylon parachute using the 54 ribbon configuration were conducted at the Sandia

Table 1 Overtest parameters

Test no.	Test date 1977	Parachute serial no.	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/m²	q_D lb/ft²	t_D, s	Δt_d, s	Δt_f, s	C_DS m²	C_DS ft²	V_i m/s	V_i ft/s	g_{max}, g's
1	2/15	584821	8.5	28	0	347	765	2194	7195	518	1700	1.53	129	2700	13.40	0.24	0.38	24	260	17	56	205
2	2/17	584822	8.5	28	0	349	770	2174	7131	523	1715	1.53	132	2750	13.42	0.21	...		...	41.5	136	138
3	4/12	584825	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	220
4	4/14	584824	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	188
5	6/30	584834	8.5	28	46	345	760	2565	8412	549	1800	1.60	134	2800	12.84	0.17	...		...	83.8	275	170
6	8/11	584837	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	240

[a] Reefing lines were precut for tests 1-4 and tests 5 and 6 were permanently reefed.

Comments:
Test 1-successful
2-bad deployment, chute failed
3-successful
4-successful, some ribbon damage
5-bad deployment, chute failed
6-good reefed overtest

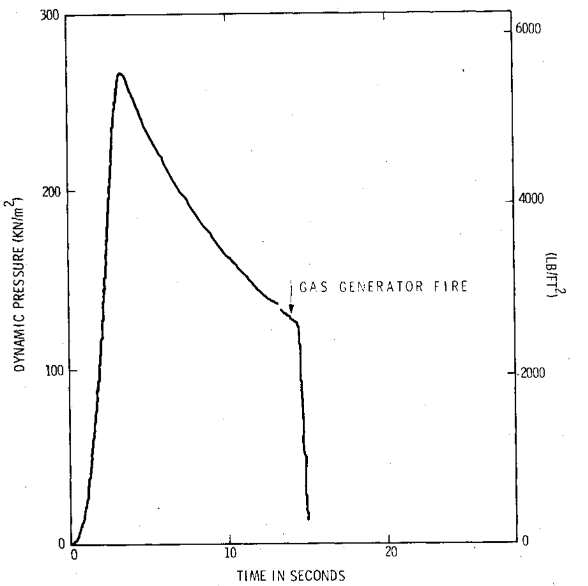

Fig. 6 Dynamic pressure vs time for test no. 3.

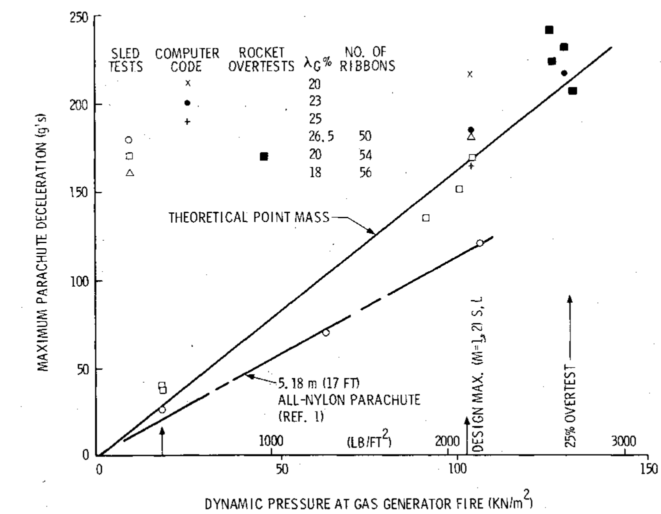

Fig. 7 Variation of maximum deceleration with dynamic pressure for the 7.3-m (24-ft) diam. hybrid parachute.

Laboratory Tonopah Test Range in Nevada. Test data are listed in Table 1. The objective was to demonstrate three successful deployments of the unreefed parachute at a dynamic pressure 25% greater than the design maximum of 102 kN/m² (2130 lb/ft²) for Mach 1.2 at sea level which would be 127.4 kN/m² (2660 lb/ft²). The first was a successful 27% overtest with the only damage being two torn 4.5-kN (1000-lb) ribbons. The second test had poor deployment with premature dumping of the suspension lines. Therefore, a bag mouth restrictor was added to all subsequent packs to prevent the bag leaves from peeling open at high-dynamic pressure. The next two tests were successful. On test no. 5, which was a 25% overtest of the reefed parachute, an extra bag lacing cut knife had been added to promote complete opening of the canopy compartment. Deployment was bad and the parachute was severely damaged. This extra cut knife was removed for test no. 6 and the reefed overtest was successful.

Results

Contraves tracking cameras were used to determine the test vehicle trajectory as shown in Fig. 3 for a typical test. The deceleration vs time is shown in Fig. 4. Peak deceleration was 200 g's. Wind tunnel tests of the 7.3-m (24-ft) diameter parachute in the NASA Ames 40×80 ft low-speed wind tunnel showed a C_DS of 24.6 m² (265 ft²). Initial overinflation is about 10% of the steady-state inflated diameter. The parachute collapses to 75% after the initial peak inflation, as shown in Fig. 5. Inflation data shown in Fig. 5 were obtained from Contraves tracking cameras. The dynamic pressure variation with time from launch is shown in Fig. 6. The variation of peak deceleration with dynamic pressure at gas generator fire is shown in Fig. 7 for all the tests. Theoretical deceleration values using a computer filling code with the CDC-6600 computer are shown. The plus symbol for a geometric porosity of 25% agrees well with the test data for the 54-ribbon design which has a geometric porosity of 20%. It is believed that due to the stiffness of the Kevlar-29 ribbons, the porosity is greater (about 5%) during inflation than for a nylon ribbon parachute.

The "dash-dot" line is shown for a 5.2-m (17-ft) diameter nylon parachute[1] for comparison. The highest deceleration of 240 g's obtained by rocket overtests (solid squares) is believed to be a new record, the highest previously known deceleration being 200 g's as reported by the author in Ref. 5. Data for a 50-ribbon design (circles) tested early in the development program are shown. By coincidence, these points fall along the curve for the 5.2-m (17-ft) nylon chute. The theoretical point mass trajectory (solid line) calculated from the filling code agrees well with the experimental data. The reefed parachute does not have lower peak deceleration than the unreefed parachute because of the 46% reefing ratio used for terminal velocity control. Peak load occurs prior to complete fill of the reefed parachute.

Conclusions

A series of six Nike rocket-boosted tests of a 7.3-m (24-ft) diameter hybrid Kevlar-29/nylon ribbon parachute were conducted. The parachute was deployed successfully four times at dynamic pressures of 124.5-131.7 kN/m^2 (2600-2750 lb/ft^2) (Mach number 1.5). A record high deceleration of 240 g's was measured. The use of Kevlar-29 in this ribbon parachute resulted in 2.25 times the drag area of an all-nylon 5.2-m (17-ft) diameter all-nylon ribbon parachute with the same pack weight and volume.

Acknowledgments

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