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AN INVESTIGATION OF THE INITIAL CENTURY SERIES RINGSAIL PARACHUTE

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SUMMARY

A program was conducted to develop new methods and techniques for the design, fabrication, packing, and drop testing of parachutes with diameters larger than 100 feet. Three large-parachute configurations were designed and experimentally flight tested. The ringsail parachute was selected for investigation because it opens quickly, it is compatible with staged inflation and cluster operation, and more data were available on fabrication, performance, and scaling of the ringsail parachute than on other types of parachutes. The program concluded with the demonstration of a single-parachute recovery of a 9750-pound payload and with the demonstration of a two-parachute-cluster recovery of a 17 000-pound payload.

INTRODUCTION

For many years, attempts to develop parachutes with diameters larger than 100 feet have encountered problems associated with the large size. State-of-the-art investigations demonstrated that large-diameter parachutes were difficult to fabricate with a high degree of quality control, posed unusual difficulties in packaging and handling, were heavier than comparable cluster systems, and were difficult to deploy.

Historically, large-payload recovery systems have employed cluster systems because such systems, available within the state of the art, provide several benefits (pendulum stability, reliability, and an easy method of achieving redundancy) not associated with large single parachutes. Previous attempts to develop large single parachutes have been restricted to several uncoordinated investigations. Data from these experiments are either unavailable or limited.

In order to develop new methods and techniques that would place large single-parachute systems on a competitive basis with clusters, the NASA Manned Spacecraft Center (MSC) initiated a program to investigate and resolve the problem areas associated with large parachutes. Initially, this program had two objectives: the development of an alternate Apollo Earth landing system (ELS) in the event the mainstream effort experienced unsolvable problems and the development of large-parachute technology that could later be incorporated into development efforts associated with large gliding devices, heavyweight-spacecraft recovery systems, and Mars and Venus landing systems. The parachute-cluster interference encountered on the Apollo configuration was solved by the inclusion of open-ring sections in each of the three main recovery parachutes. Primary emphasis was then placed on the second objective.

The approach selected in developing large-parachute technology was to design and investigate a large single parachute capable of recovering a 9500-pound payload. Then, with that base line established, payload capability would be increased to 20 000 pounds in a later effort. This document discusses the efforts associated with the design, testing, and successful demonstration of a single-parachute recovery of a 9500-pound payload and the successful recovery of a 17 000-pound payload with a two-parachute cluster of large-diameter parachutes.

The ringsail type of canopy used singly on Project Mercury and the Gemini Program and in clusters on the Apollo Program was selected for extrapolation to larger sizes because it was the best candidate for reducing inflation time and because considerable performance data, scaling information, and advanced fabrication techniques existed for this type of parachute. The development task was divided into three related efforts: an in-house investigation of the deployment and inflation characteristics of the initial large-parachute design; a series of drop tests at the instrumented test range at El Centro, California, to obtain aerodynamic performance data; and an investigation of inflation characteristics in a cluster configuration.

During this program, three different configurations were investigated. The initial design was based on the extrapolation of largely empirical data, and two configuration changes were made in an attempt to solve problem areas that emerged during the investigation. The final design proved to be satisfactory.

The design, testing, and test results for each configuration are presented in this paper. Appendix A discusses design factors, and appendix B contains descriptions of the El Centro drop tests. Descriptions of the test vehicles, instrumentation, and test photography are included in appendix C.

SYMBOLS

A strength

A_P allowable strength factor, ueokγls cos ϕ

C_D drag coefficient

$C_{D,o}$ drag coefficient based on nominal diameter

D. F. design factor, S. F./A_P

D_o parachute nominal diameter

D_R	reefed diameter
e	abrasion loss factor
F_{DR}	force (disreefed)
F_o	force (full open)
F_R	force (reefed open)
F_S	force (line stretch)
h	height
k	fatigue loss factor
L_s	line length
l	vacuum loss factor
o	humidity loss factor
P_A	allowable strength, $A_P P_R$
P_r	rated minimum unit strength
P_Z	pressure related to number of lines
q	dynamic pressure (line stretch)
q_e	dynamic pressure (equilibrium conditions)
S	area
S_o	nominal canopy area
S. F.	design safety factor, ultimate load/limit load
s	load distribution factor
T	time
T_F	time (free fall)
u	joint efficiency factor

V	velocity
V_{av}	average velocity
W	weight
W_T	weight, total
X_R	opening shock coefficient (reefed)
γ	temperature loss factor
Δh	height differential
ΔT	time differential
ρ	density of air
ϕ	confluence angle

Subscripts:

DR	disreefed
R	reefed

DISCUSSION

Requirements

The design and operational criteria established for the parachute system were based on dynamic conditions that generally reflected Apollo requirements (table I). A goal of 180 pounds was established for the total weight of the canopy and lines.

The 124.5-Foot-D_0 Ringsail Parachute

Design. - The basic canopy selected was quarter spherical (fig. 1), and the canopy area needed was calculated to be 12 000 ft^2, based upon a $C_{D,o}$ of 0.85 and a desired descent rate of 30 fps. This area established the nominal canopy diameter of 124.5 feet. The quarter-spherical design provides a considerable amount of fullness, which reduces circumferential stresses and, consequently, the likelihood of gore failure due to circumferential loading. For the first design, excess fullness was deliberately employed to protect against failures caused by excessive circumferential loads. Radial infolding during the inflation process is indicative of excess fullness, and this infolding was expected to occur.

A common design practice in determining the number of canopy gores on smaller ringsail parachutes has been to select a number that lies between 76 and 92 percent of the nominal canopy diameter and is divisible by 4 to allow even grouping of the suspension lines on the risers. For the initial 124.5-foot-D_o canopy, this practice was followed, and the number of gores was established at 112. Suspension-line length was established as $1.4D_o$, based on extrapolation of Mercury and Apollo ringsail parachute data.

Under the deployment conditions specified, a design-limit opening force of 23 000 pounds was estimated from empirical data. With this load and a design factor of 1.9 (appendix A), the maximum force in each suspension line was calculated to be approximately 390 pounds. Because the parachute was to undergo repeated testing, 550-pound lines (rather than the next smaller standard size of 400 pounds) were used. To make the strength of the radial tapes commensurate with the 550-pound suspension lines, double 300-pound tapes were used in the main (radial) seams. Fabrics for the individual canopy sails were selected to resemble the Apollo ringsail parachute design, with 2.25-ounce nylon cloth in the crown area and 1.1-ounce nylon ripstop in the remainder of the canopy.

Previous experience with smaller diameter ringsail parachutes indicated that inflation rate increased as canopy diameter increased. In order to prevent excessive opening loads and canopy failure caused by too rapid inflation, the canopy geometric porosity was increased (fig. 2) to slow the inflation rate. This procedure had proved effective on smaller ringsail parachutes.

The initial selection of reefing parameters was based on the Gemini reefing system which, unlike the three-parachute cluster used on Apollo, employed a single ringsail parachute for recovery. A single-stage reefing system of 11.5 percent D_o for 6 seconds was chosen.

Fabrication and packing. - Fabrication tolerances were based on final dimensions rather than on pattern dimensions (fig. 3) and required considerable time and careful attention to panel and radial alinement. A 100-percent inspection was made on the marking and cutting of suspension lines, vent lines, skirt band, vent band, radial tapes, sails, and cutter pockets. In-process examination of the parachute assembly during fabrication consisted of ensuring the correct assembly of parts and checking the general workmanship and quality of the parachute. Inspection of the finished parachute consisted of measuring 10 percent of the total number of the following critical parachute dimensions and comparing them with the dimensions specified on the assembly drawing: vent gore width, skirt gore width, radial gore length, vent-line length, and suspension-line length. These measurements were made at approximately every 10th gore to obtain a representative cross section of the parachute.

Rigging and packing the parachute proved to be a two-man job. Because a table of sufficient length was not available for the rigging and packing process, it was necessary to route the lines and risers around a wooden pulley (shown in fig. 4) to maintain tension on the parachute for combing the lines and flaking the canopy. This particular portion of the rigging process required special care to ensure that the lines did not become crossed.

Testing. - Six preliminary drop tests of the 124.5-foot-D_o ringsail parachute were conducted at MSC to observe inflation characteristics and to evaluate the selected reefing parameters. Table II summarizes the test conditions and results obtained from each test. During the first test, the drogue parachute (which extracts the main parachute) failed to release from the test vehicle, and consequently, the main parachute did not deploy. During the remaining five tests, the parachute deployed satisfactorily and developed a large, bulbous shape during the reefed stage. Inflation loads exceeded the maximum predicted value on three of the tests; however, this parachute design apparently had an ample margin of safety because no major damage was encountered.

The test summary (table II) and the force-time histories of each test (figs. 5 to 9) represent the total quantitative data obtained during these tests. All tests were conducted at approximately the same initial conditions; therefore, the results should have been comparable. However, the force-time histories show considerable variation in the deployment loads. Review of the test film revealed that the reefed shape of the canopy varied considerably because of infolding during the inflation process.

A review of the inflation-load histories on tests 2 to 5 indicated that terminal velocity conditions were not being achieved prior to disreefing with the 6-second delay-reefing cutter parachutes. Therefore, maximum benefit of the reefed stage was not achieved, and higher-than-expected full-inflation loads were the result. The reefed inflation interval was extended to 12 seconds for test 6 to ensure steady-state conditions at disreef. As expected, this test showed a considerable reduction in the magnitude of the full-inflation load. An examination of the opening force-time history from test 6 indicates that reefed steady-state velocity conditions were achieved after a reefed interval of approximately 10 seconds. It may be concluded that 10-second delay-reefing-time cutter parachutes would be closer to optimum for the 11.5 percent reefing ratio.

Figure 10 indicates the canopy areas that were damaged during the test program. Only repairable damage (blown panels, holes, tears, burns, etc.) has been indicated by the blackened panels. Following test 2 (the first actual deployment of the parachute), the canopy showed numerous strains (weave separation in the nylon cloth panels); however, this type of damage did not seem to increase as the test series continued. Overall, the damage was relatively minor and seemed to occur within a narrow band along the parachute packing axis (gores 1 and 56). This damage pattern indicated that a revision to the packing procedure was needed or that a new deployment bag design was necessary, or both. The six tests indicated that the 124.5-foot-D_o ringsail parachute could be fabricated, packed, and deployed successfully. As expected, the canopy did exhibit the radial infolding characteristic of the excess fullness employed in the design.

The 127.0-Foot-D_o Ringsail Parachute

Design. - After the preliminary drop-test evaluation of the 124.5-foot-D_o parachute, a second configuration was designed to eliminate the excess fullness, simplify the gore profile, and reduce the canopy weight. This second configuration was identified as the 127.0-foot-D_o ringsail parachute.

An evaluation of the inflated shape of the initial (124.5-foot-D_o) configuration indicated that the inflated profile could be approximated more closely by a biconical gore shape, and a 30°-60° biconical profile was selected for the 127.0-foot-D_o design. This type of gore design eliminates the excess fullness observed in the initial configuration. The number of gores and suspension lines remained unchanged. Reduction in canopy weight was achieved by designing for reduced peak opening loads, which again necessitated an increase in crown porosity. The total geometric porosity for the new configuration was 2.81 percent S_o, as opposed to 1.96 percent for the 124.5-foot-D_o version.

Fullness distributions: The 127.0-foot-D_o parachute was manufactured in a second fullness distribution when initial drop tests indicated that the original fullness was inadequate. On most ringsail parachute designs, a transition point occurs in sail trailing-edge fullness approximately one-third of the canopy radius down from the vent. At this point, the fullness is usually reduced to zero. For the original configuration, it was decided to extend the zero fullness all the way up to the vent in order to provide more effective control of the crown shape. The lower-sail-edge fullness was made a constant 10 percent to produce an average overall fullness consistent with previous ringsail canopies.

The initial three drop tests of this design identified an area of stress concentration in the crown sail trailing edges due to a lack of fullness. To relieve this stress concentration, a new fullness distribution was selected that consisted of sail trailing-edge fullness of 12 percent at the vent and tapering to 10 percent at the top of ring 10. The 10-percent fullness was then held constant down to the skirt.

Material modifications: In addition to the fullness changes, two material changes were made to the original configuration when the drop tests indicated insufficient cloth strength. Materials selected for the original configuration are shown in figure 11. Three cloth weights were used: 2.25-ounce nylon in rings 1 to 3; 1.6-ounce nylon in rings 4 to 7; and 1.1-ounce nylon in rings 8 to 20. The expected peak reefed-open force was estimated to be 23 000 pounds; therefore, 400-pound nylon cord was selected for the 112 suspension lines. Radials were fabricated of 2-ply, 200-pound tape. To improve the tear resistance of the sails, reinforcing tape was sewn to the trailing edges of rings 1 to 10 and to the leading edges of rings 1 to 8. Tape strength (fig. 11) was based on experimentation and structural analysis.

In the first modification, no changes were made in the cloth distribution, radial strength, or suspension-line strength. However, the strength of the leading- and trailing-edge tape was doubled in rings 4 to 10, and 90-pound tape was added to the trailing edges of rings 11 and 12 (fig. 12).

In the second modification, nylon weighing 2.25 oz/yd^2 was used in rings 1 to 5, 1.6-ounce nylon was used in rings 6 and 7, and 1.1-ounce nylon was used in rings 8 to 20. Radial and suspension-line strengths remained unchanged. The leading- and trailing-edge tapes were not changed, with the exception that 70-pound tape, instead of 90-pound tape, was used on the trailing edges of rings 11 and 12 (fig. 13).

The 127.0-foot-D_o parachute was equipped with a single-stage reefing system. Based upon results obtained during tests of the 124.5-foot-D_o parachute, the first 127.0-foot-D_o configuration tested was reefed to 11 percent for 8 seconds. The effect of the increased porosity on the parachute inflation characteristics was greater than expected, and the reefing ratio had to be progressively increased to 16 percent before a satisfactory reefed stage was obtained.

Fabrication and packing. - The same techniques developed and refined during the 124.5-foot-D_o ringsail parachute tests were employed in fabricating and packing the 127.0-foot-D_o ringsail parachute.

Testing. - Five tests were conducted at El Centro, California, using the 127.0-foot-D_o biconical design, but none were completely successful. Table III summarizes the five tests conducted with this design. Each test, except test 4 (on which a failed pilot riser destroyed the canopy), resulted in structural failure of certain areas of the canopy, although the deployment loads were less than the design value of 23 000 pounds. The failure was usually manifested in one gore of the canopy splitting from vent to skirt. The initial point of failure was localized from rings 5 to 7, although the current methods of analysis indicated the canopy to be structurally sound in that area. However, these analyses did not consider nonuniform loading of the canopy caused by irregularities in the shape of the parachute or by cloth acceleration during the inflation process. In an attempt to eliminate the structural failures, the canopy strength was increased progressively during the test program by adding reinforcing tape, by changing the cloth distribution, and by revising the fullness distribution. However, this approach proved unsuccessful. All five tests indicated that the canopy fullness was inadequate and that its structural load-bearing capabilities were inadequate in some areas. Consequently, investigation of the 127.0-foot-D_o design was abandoned. Appendix B presents a detailed description of each test.

The 128.8-Foot-D_o Ringsail Parachute

Design. - Analysis of the results of the 127.0-foot-D_o ringsail parachute drop tests indicated that the reduction in fullness and structural capability from that of the 124.5-foot-D_o parachute, although substantiated by the best available stress analysis, was far too severe and that only minimal departure from the 124.5-foot-D_o configuration was required. Also, at this point, the payload design criterion was increased from the 9500 pounds used for the previous configuration to 9750 pounds in order to approximate more nearly the then current Apollo weight. This heavier payload necessitated an increase in diameter to 128.8 feet.

The selected gore shape (fig. 14) represented a simplified version of the 124.5-foot-D_o ringsail canopy, and the fullness distribution (fig. 15) represented a conservative simplification of the 124.5-foot-D_o design.

The crown porosity was reduced from 2.81 percent S_o for the 127.0-foot-D_o configuration to 2.08 percent S_o for the 128.8-foot-D_o configuration. This reduction was made so that the reefed drag characteristics of the 128.8-foot-D_o configuration would become more consistent with those successfully demonstrated by the 124.5-foot-D_o parachute. Vertical tapes were added to the center line of each gore in the crown section to control the effective porosity and to make the initial reefed opening more uniform. The gore geometry selected to produce the desired porosity is shown in figure 14.

The 128.8-foot-D_o parachute was fabricated in two versions, which were aerodynamically identical but differed in materials selection. Table IV is a summary of materials used in both versions.

Selection of the canopy materials was based on the structural analysis and the results of tests of the two previous configurations. A slightly conservative approach was taken on the 128.8-foot-D_o design: 2.25-ounce nylon cloth was used in rings 1 to 5; 1.6-ounce nylon ripstop was used in rings 6 to 8; and 1.1-ounce nylon ripstop was used for the remainder of the parachute. On the lightweight configuration, 2.25-ounce nylon cloth was used in rings 1 to 4; 1.6-ounce nylon ripstop was used in rings 5 to 7; and 1.1-ounce nylon ripstop was used for the remainder of the canopy.

A 1000-pound tape was added to the canopy at the top of ring 9 on both configurations. The purpose of this tape was to stop progressive failures such as those incurred with the 127.0-foot-D_o parachute. All other tape was installed to increase the tear resistance of the sail edges.

The maximum and minimum estimated reefed- and disreefed-open loads are shown in tables V and VI and are plotted as a function of reefing ratio in figure 16. By using these load values as design loads, 450-pound suspension lines and 200- and 300-pound radial tapes were selected. Table VII compares the design details of the 128.8-foot-D_o parachute with the design details of the 124.5-foot-D_o and the 127.0-foot-D_o parachutes.

<u>Fabrication and packing</u>. - The fabrication and packing techniques developed and used during the previous two test series were successfully employed for this test series.

<u>Testing</u>. - Two single-parachute tests and one cluster drop test of the 128.8-foot-D_o ringsail parachute were conducted at the joint Parachute Test Center, El Centro, California. A detailed description of these tests is contained in appendix B. Single tests of the lightweight and heavyweight versions were conducted at essentially identical conditions to provide a basis for evaluating canopy strength. No damage occurred to the heavyweight version, whereas two rips occurred in the lightweight version, which was subjected to essentially identical peak loading. Following disreefing of the lightweight configuration, a rip appeared near ring 5 of gore 3. This damage progressed upward to the vent band and downward to the top of ring 9, where it was stopped by the 1000-pound tape. At that time, another rip began in gore 1 at the top of

ring 9 and continued downward to the skirt band. The rate at which the rip progressed was slower than that experienced with the 127.0-foot-D_o parachute. The 1000-pound tape was effective in stopping the initial rip.

Because the loads on the two single-parachute tests were similar, the load in ring 5 of the lightweight configuration may be marginal for 1.6-ounce material. This conclusion is based upon the following observations:

1. The progression rate of the rip was relatively slow.

2. The 1.1-ounce material was adequate in this region of the ringsail parachute when the parachute was tested at a lower dynamic pressure.

3. The 2.25-ounce material was adequate in this region of the heavyweight 128.8-foot-D_o ringsail parachute when the parachute was tested at approximately the same dynamic pressure.

Both the lightweight and the heavyweight versions of the parachute deployed and inflated satisfactorily, assuming a large, bulbous inflated shape in the reefed stage. Opening loads were essentially balanced at 26 000 pounds. The steady-state rate of descent for both versions of the parachute was approximately 27 fps.

The cluster test was conducted to evaluate the inflation characteristics of the 128.8-foot-D_o parachute when used in a cluster. Both canopies were of the heavyweight design. The payload was ballasted to 17 000 pounds.

In this test, deployment of both parachutes was satisfactory; however, aerodynamic blanketing of one parachute, simular to that encountered in the Apollo Program, was evident during the reefed stage. Table III indicates the maximum reefed force to be in reasonable agreement for both parachutes; however, as parachute inflation continued, blanketing of parachute 1 became more severe (as is evident from the difference in the loads at disreefing).

The full-open loads were in poor agreement because of the considerably greater degree of development of parachute 2. The maximum total reefed and disreefed loads of 39 000 and 39 500 pounds, respectively, were almost equal. This similarity confirms that the 13-percent reefing ratio for 8 seconds is nearly optimum at the design conditions selected.

Following disreef, both canopies opened to a fully inflated condition. The steady-state rate of descent was 26 fps.

Only minimal damage occurred, and this test was considered to be a successful demonstration of cluster operation of Century series ringsail parachutes and indicated the feasibility of this approach for large-payload recovery. The aerodynamic blanketing situation encountered during inflation was similar to that encountered in the Apollo Program. This problem was solved for the Apollo parachute system by the incorporation of an open slot in ring 5 of each of the parachutes. The same method should be applicable to the Century series parachutes.

CONCLUDING REMARKS

Recovery of heavyweight vehicles by single and clustered large-diameter ringsail parachutes with diameters in excess of 100 feet has been demonstrated at realistic spacecraft dynamic conditions. Techniques were developed to fabricate the large canopies to finished dimensions rather than to pattern dimensions. These new techniques proved that large canopies could be manufactured with closely controlled tolerances and with a level of quality consistent with that of smaller parachutes. Packing techniques were developed and successfully employed without marked difficulty.

Stress distribution within the canopy of the biconical ringsail design was more critical than within the modified spherical design. A drag coefficient of 0.9, calculated from data obtained during the first test of the 128.8-foot-nominal-diameter ringsail parachute, was confirmed by later drop tests.

Panels located in circumferential rings 5 to 7 of the 127.0-foot-nominal-diameter biconical ringsail parachute were particularly sensitive to localized dynamic conditions during deployment and inflation. These conditions cannot be predicted with current structural analyses.

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TABLE I. - PARACHUTE DESIGN REQUIREMENTS

Single parachute	
Payload weight, lb	9500
Descent rate at 5000-ft altitude (q_e = 0.92 psf), fps	30
Deployment altitude, ft	15 000
Deployment dynamic pressure (design), psf	64
Deployment dynamic pressure (ultimate), psf	96
Pendulum oscillation (maximum), deg	15
Two-parachute cluster	
Payload weight, lb	17 000
Descent rate at 5000-ft altitude (q_e = 0.92 psf), fps	30
Deployment altitude, ft	15 000
Deployment dynamic pressure (design), psf	64
Deployment dynamic pressure (ultimate), psf	96
Pendulum oscillation (maximum), deg	15

TABLE II. - SUMMARY OF RESULTS — 124.5-FOOT-D_o RINGSAIL PARACHUTE

[Drop-aircraft velocity on all tests was 130 knots]

Test	Drop attitude, ft m. s. l.	psf (a)	W_T, lb	Extraction drogue parachute			Pilot parachute	Main parachute			Main parachute deployment force				Total downtime, sec
				D_o, ft	D_R, ft	T_F, sec	D_o, ft	D_o, ft	D_R/D_o, percent	T_R, sec	F_S, lb	F_R, lb	F_{DR}, lb	F_o, lb	
[b]1	3500	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	6000	59	9650	22	18.8	5.0	None used	124.5	11.5	6.0	6100	17 100	19 000	27 100	135
3	3600	59	9650	22	18.8	5.0	6.0	124.5	11.5	6.0	6300	19 400	16 600	27 900	60
4	3600	67	9650	22	12.9	5.0	6.0	124.5	11.5	6.0	5300	13 600	11 700	22 400	76
5	3600	67	9650	22	12.9	5.0	6.0	124.5	11.5	6.0	6600	21 600	13 500	23 900	61
6	3600	67	9650	22	12.9	5.0	6.0	124.5	11.5	12.0	6200	15 100	9 700	19 300	51

[a]Dynamic pressure calculated from trajectory analysis.

[b]Drogue parachute did not release.

TABLE III. - SUMMARY OF EL CENTRO DROP TESTS

Parachute nominal diameter, D_o, ft	Serial no.	Reefing parameter: Reefing ratio, percent D_o	Reefing parameter: ΔT, sec	Deployment altitude, ft m. s. l.	Deployment dynamic pressure, psf	Snatch force, lb	Maximum reefed force, lb	Disreef force, lb	Maximum full-open force, lb	Descent rate, fps (a)	System weight, lb
127.0	1	11	8	15 010	71.5	8 000	15 500	10 350	23 650	--	9 714
127.0	1	13	8	15 410	67.2	8 200	16 000	10 970	20 600	--	9 730
127.0	1	16	8	15 747	69.3	6 875	21 250	12 000	19 750	--	9 752
127.0	2	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
127.0	3	16	8	15 365	67.8	10 500	21 350	10 500	21 950	--	9 755
[c]128.8	M-1	12.5	8	15 640	101.7	10 150	25 650	11 100	24 775	28.4	9 786
[d]128.8	L-1	12.5	8	15 867	95.3	10 000	26 800	11 100	24 200	30.0	9 762
128.8 (cluster)	M-1	[e]13	[e]8	[e]10 246	[e]76.2	8 000	19 400	7 050	13 800	[e]28.0	[e]17 720
	M-2					5 500	21 800	13 900	27 600		

[a]Velocity at 5000-foot altitude.

[b]Parachute failed — defective pilot parachute link.

[c]Heavyweight version (230 pounds).

[d]Lightweight version (205.6 pounds).

[e]These values were obtained for M-1 and M-2 combined.

TABLE IV. - LIST OF MATERIALS FOR 128.8-FOOT-D_o RINGSAIL PARACHUTE

Section	Heavyweight version (230 lb)			Lightweight version (205 lb)		
Vent lines	550-lb nylon cord			450-lb nylon cord		
Vent band	4000-lb, 1-in. web			4000-lb, 1-in. web		
Ring	Cloth weight, oz/yd^2	Tape		Cloth weight, oz/yd^2	Tape	
		P_r, lb	Width, in.		P_r, lb	Width, in.
1	2.25	200	1.06	2.25	200	1.06
2	2.25	200	1.06	2.25	200	1.06
3	2.25	200	1.06	2.25	200	1.06
4	2.25	90	.62	2.25	90	.62
5	2.25	90	.62	1.6	90	.62
6	1.6	90	.62	1.6	90	.62
7	1.6	90	.62	1.6	90	.62
8	1.6	90	.62	1.1	70	.62
9	1.1	[a]1000	.50	1.1	[b]1000	.50
10	1.1	[a]70	.62	1.1	[b]70	.62
11	1.1	[a]70	.62	1.1	[b]70	.62
12	1.1	[a]70	.62	1.1	None[c]	--
13	1.1	None[c]	--	1.1	None[c]	--
14	1.1	None[c]	--	1.1	None[c]	--
15	1.1	None[c]	--	1.1	None[c]	--
16	1.1	None[c]	--	1.1	None[c]	--
17	1.1	None[c]	--	1.1	None[c]	--
18	1.1	None[c]	--	1.1	None[c]	--
19	1.1	None[c]	--	1.1	None[c]	--
20	1.1	None[c]	--	1.1	None[c]	--
21	1.1	None[c]	--	1.1	None[c]	--
Skirt band	1000-lb, 0.5-in. web			1000-lb, 0.5-in. web		
Radials (2 each)	300-lb, 1-in. tape			200-lb, 1.6-in. tape		
Suspension lines	550-lb nylon cord			450-lb nylon cord		

[a]On leading edge only.
[b]On trailing edge only.
[c]Triple-selvage cloth.

TABLE V. - PREDICTED REEFED-OPEN FORCES

Parameter	11.5-percent reefing ratio	12.5-percent reefing ratio	13.0-percent reefing ratio	13.5-percent reefing ratio
Ratio, $(C_DS)_R/C_DS$	0.070	0.089	0.098	0.107
Reefed drag area, $(C_DS)_R$, ft^2	738	938	1033	1130
Unit load, $W/(C_DS)_R$, psf	13.2	10.4	9.43	8.62
Coefficient X_R				
Maximum	52	45	42	39
Minimum	40	34	32	30
Opening force, F_R (at $q = 64$ psf), lb				
Maximum	24 600	27 000	27 800	28 200
Minimum	18 900	20 400	21 200	21 700

TABLE VI. - PREDICTED FULL-OPEN FORCES

Parameter	11.5-percent reefing ratio	12.5-percent reefing ratio	13.0-percent reefing ratio	13.5-percent reefing ratio
Ratio, $(C_DS)_{DR}/C_DS$	113	134	145	155
Drag area, $(C_DS)_{DR}$, ft^2	1192	1413	1530	1635
$q_{DR} = \dfrac{1.07(9750)}{(C_DS)_{DR}}$, psf	8.76	7.38	6.82	6.38
Opening force, F_o, lb				
Maximum = $0.393\ C_DSq_{DR}$	36 300	30 600	28 300	26 500
Minimum = $0.303\ C_DSq_{DR}$	28 000	23 600	21 800	20 400

TABLE VII. - CENTURY SERIES RINGSAIL PARACHUTE SUMMARY

Parameter	124.5-ft-D_o parachute	127.0-ft-D_o parachute	128.8-ft-D_o parachute
Canopy profile	Ogival	Biconical	Ogival
Apex angle, deg	15	30	15
Canopy area, S_o, ft	12 171	12 662	13 035
Number of gores (and lines)	112	112	112
Number of rings	17	20	21
Width of rings (cloth), in.	42	36	36
Number of riser branches	8	8	8
Length of lines, ft	172	143	145
Length of risers, ft	3	3	3
Length of main riser, ft	1	32	32
Rigging length ratio, L_s/D_o	1.40	1.15	1.15
Geometric porosity, percent S_o			
Vent	.15	.22	.15
Crown slots	1.81	2.59	1.93
Crown total	1.96	2.81	2.08
Crescent slots	3.18	4.24	4.24
Fabric porosity, percent S_o	3.54	3.46	3.45
Total porosity, percent S_o	8.68	10.51	9.77
Weight of canopy and lines, lb	218	200	230
C_DS (design)	10 330	10 330	10 550

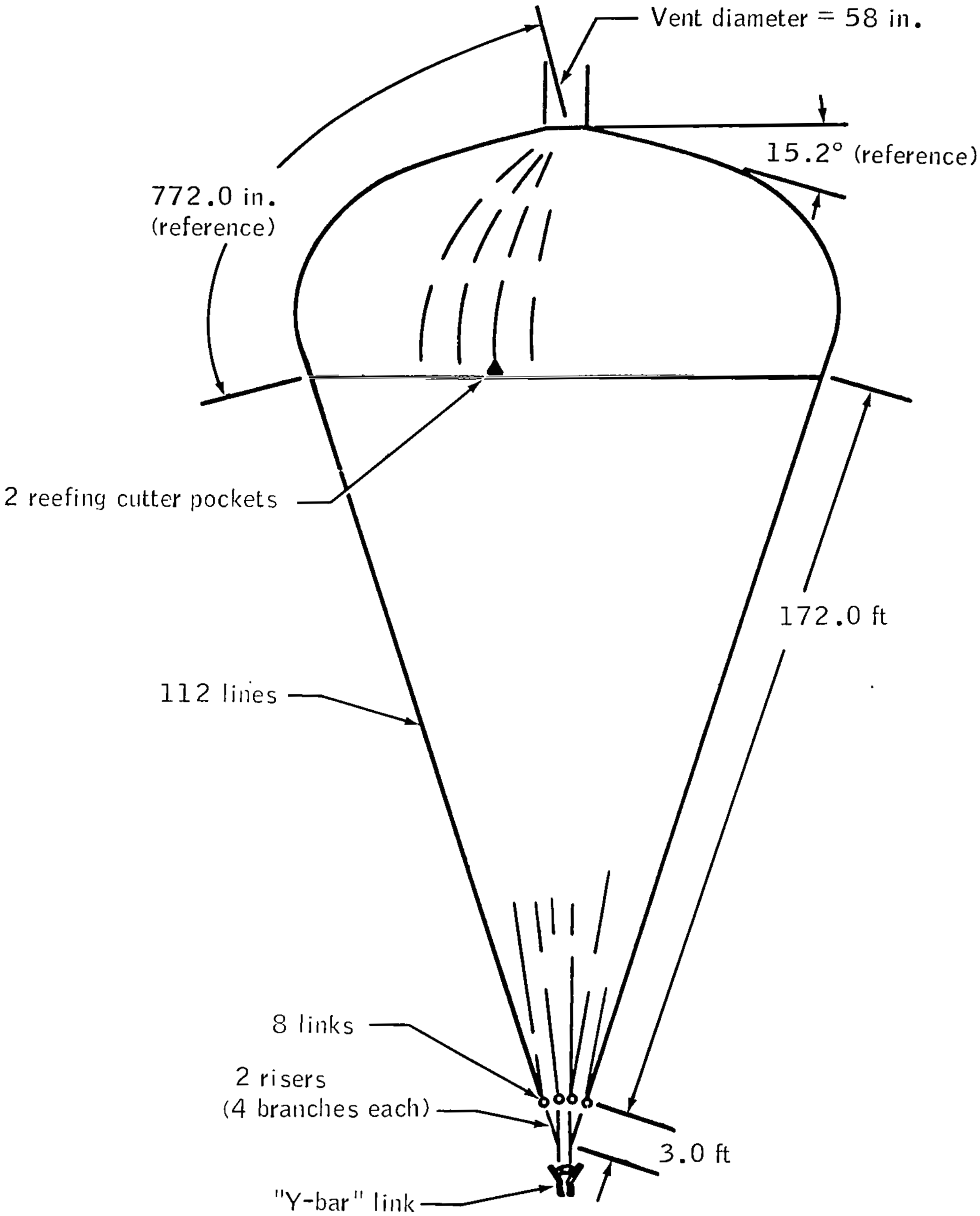
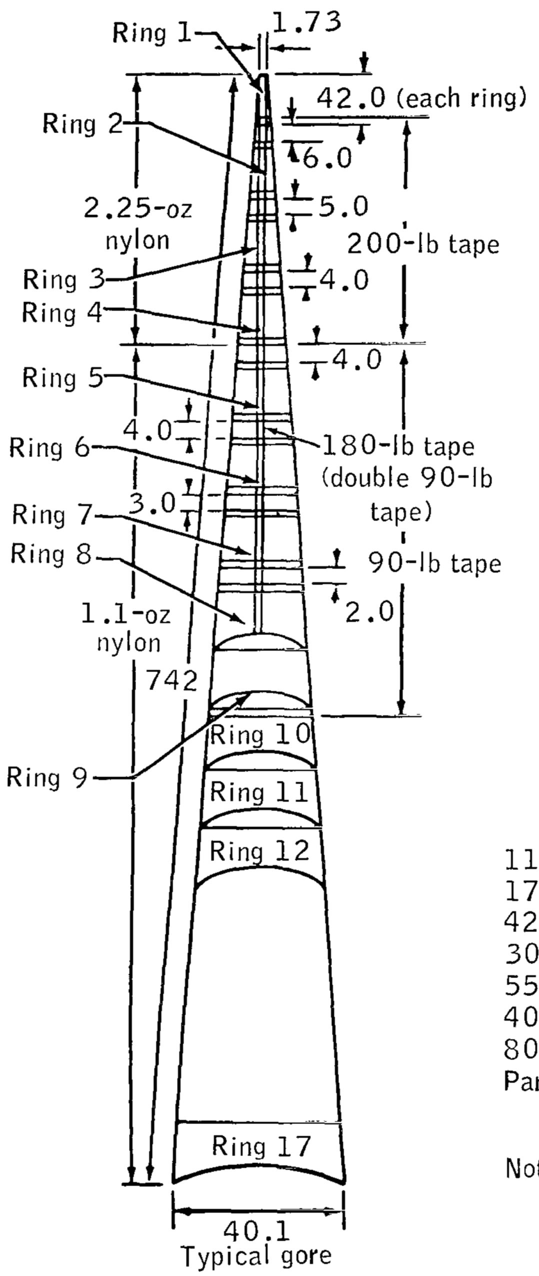
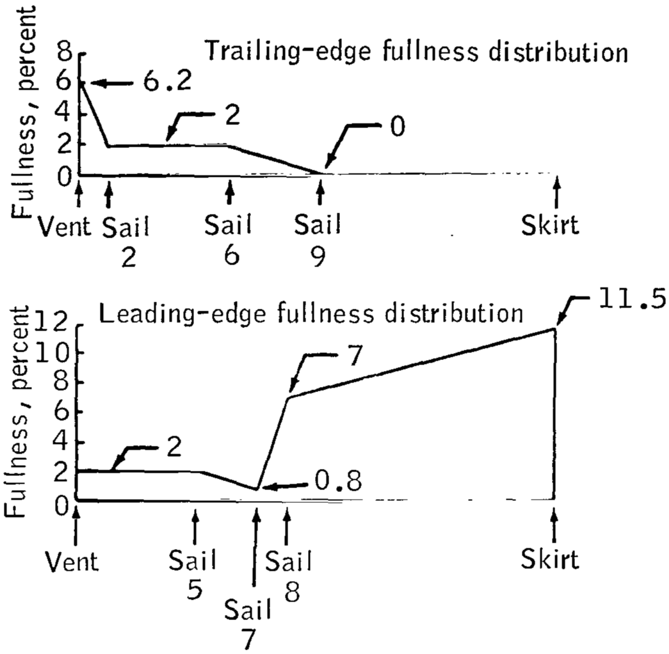


Figure 1. - Profile of 124.5-foot-D_o ringsail parachute.





112 gores
17 rings
42-in. cloth sails
300-lb radials (doubled)
550-lb suspension lines (172 ft long)
4000-lb vent band
800-lb skirt band (300 and 500-lb tape)
Parachute wt = 218 lb (canopy and suspension lines)

Note: All dimensions are given in inches unless otherwise specified

Figure 2. - Design details of typical gore — 124.5-foot-D_o ringsail parachute.

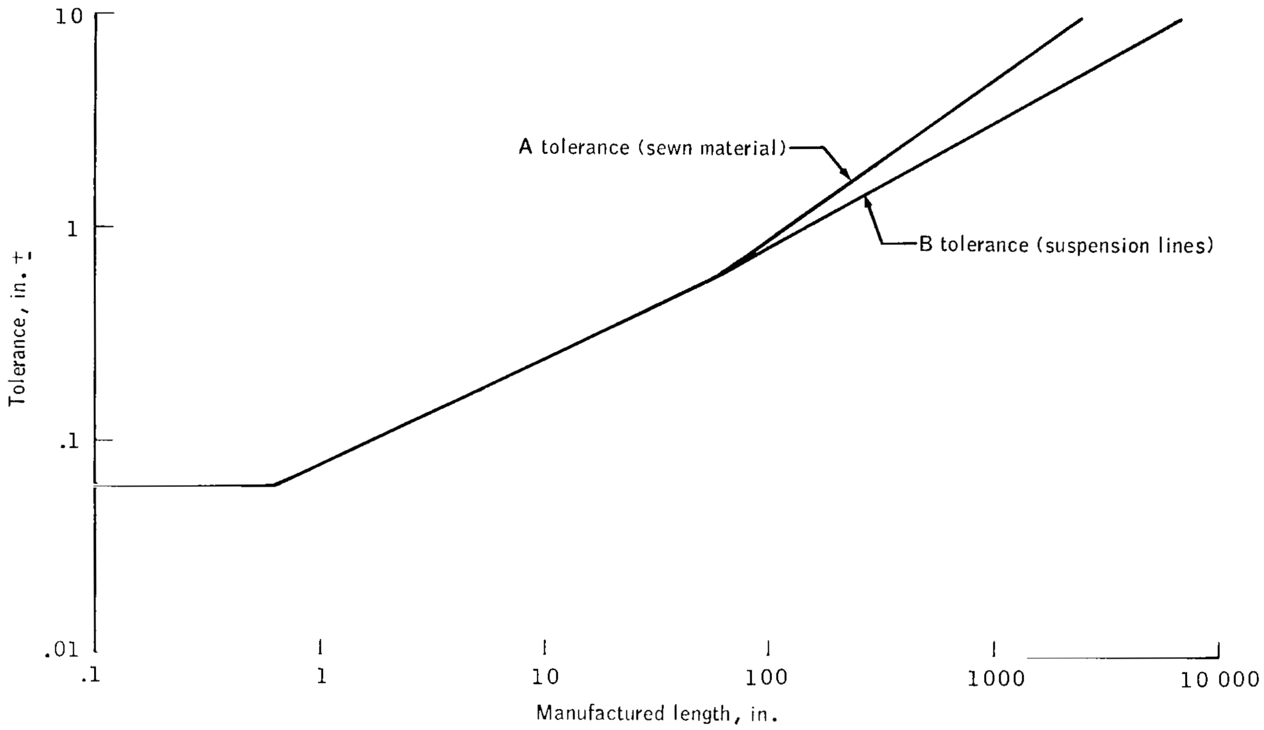


Figure 3. - Century series ringsail parachute fabrication tolerances.

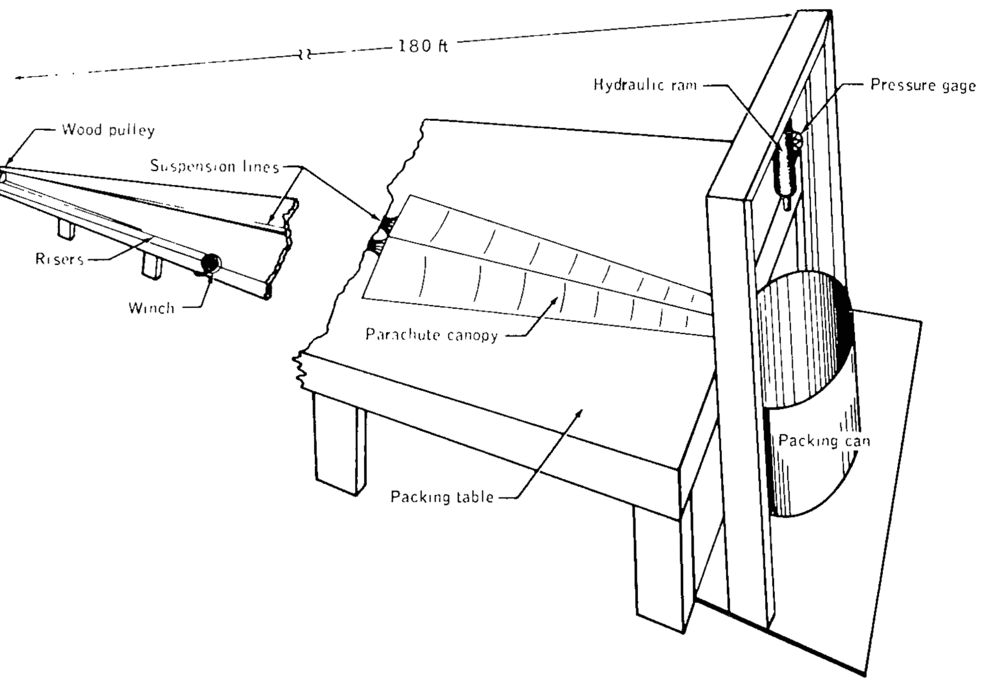


Figure 4. - Parachute packing table.

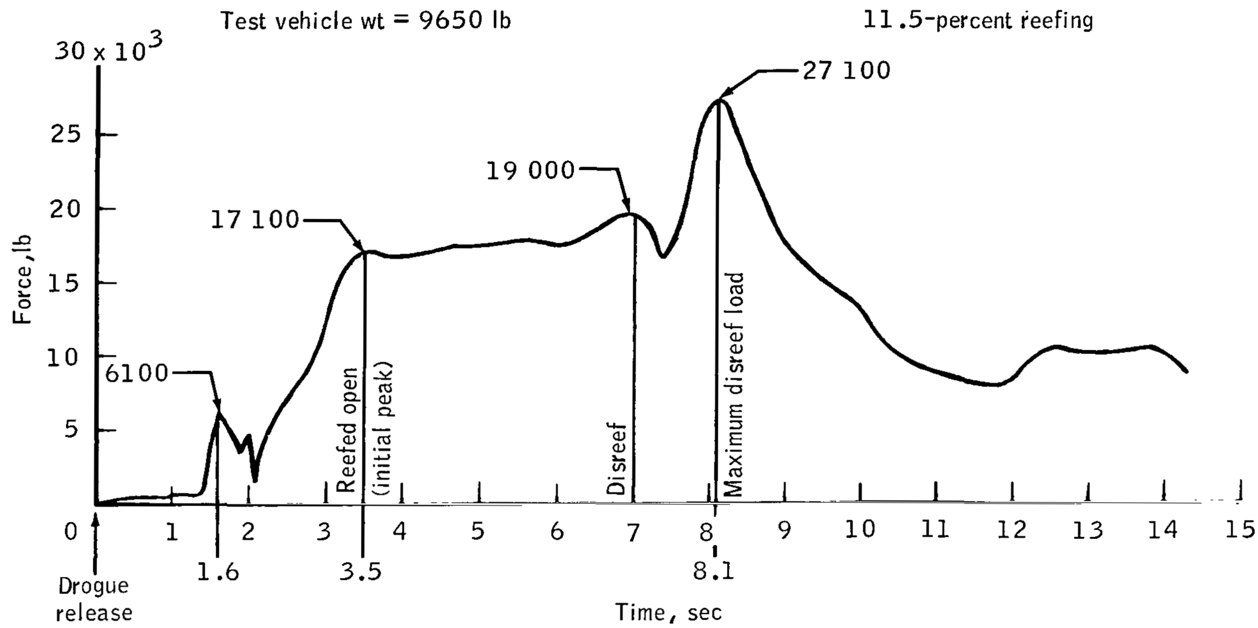


Figure 5. - Main parachute force-time history, test 2, MSC (124.5-foot-D_o canopy).

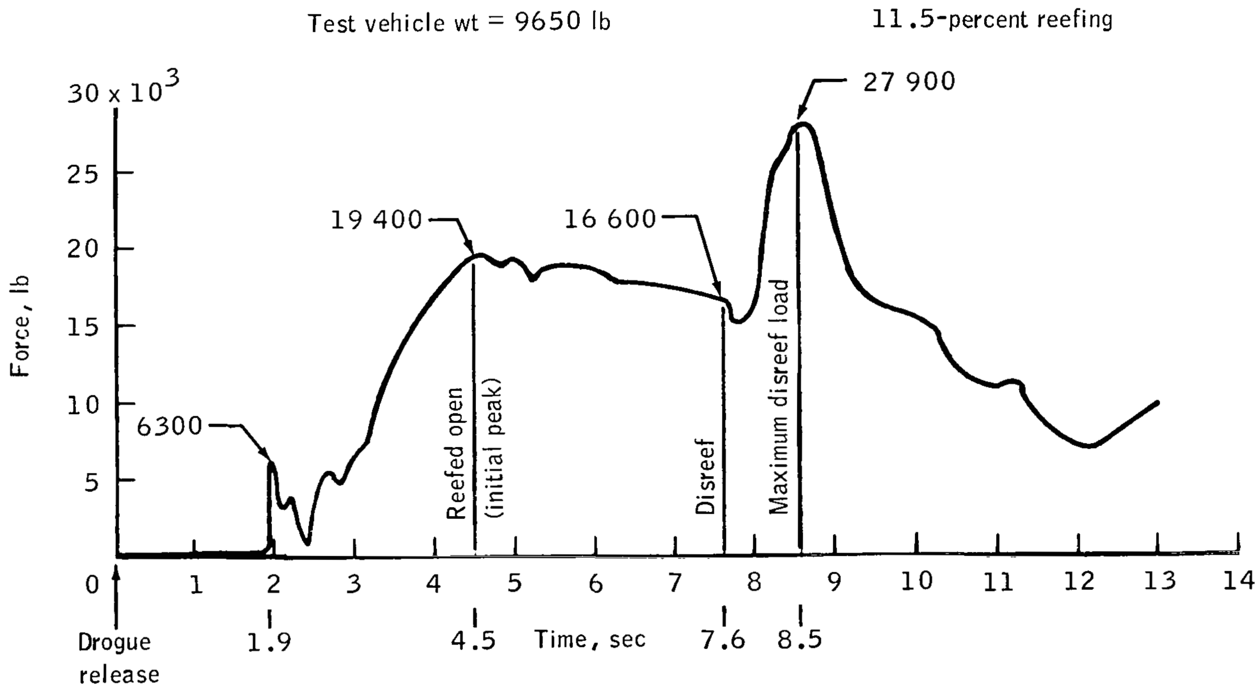


Figure 6. - Main parachute force-time history, test 3, MSC (124.5-foot-D_o canopy).

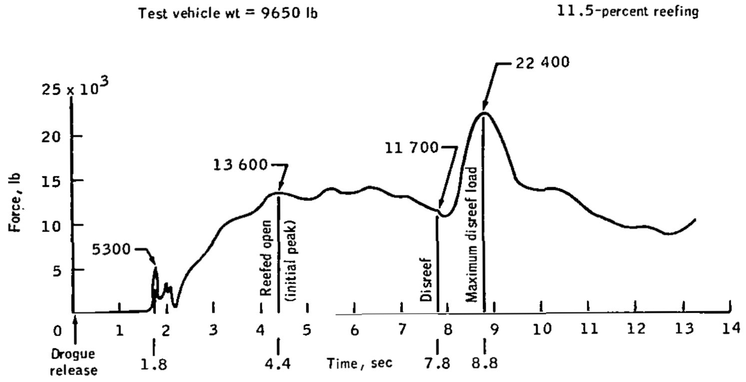


Figure 7. - Main parachute force-time history, test 4, MSC (124.5-foot-D_O canopy).

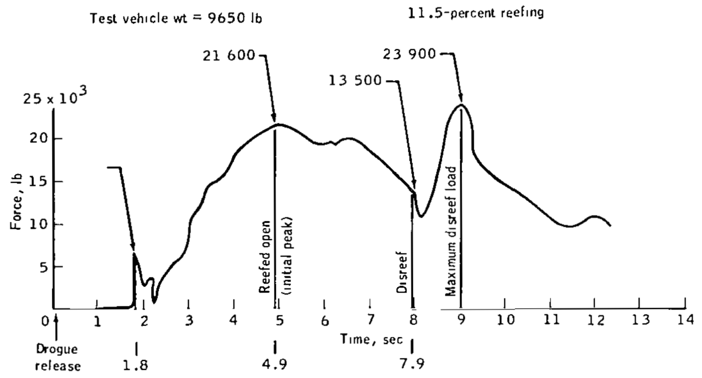


Figure 8. - Main parachute force-time history, test 5, MSC (124.5-foot-D_O canopy).

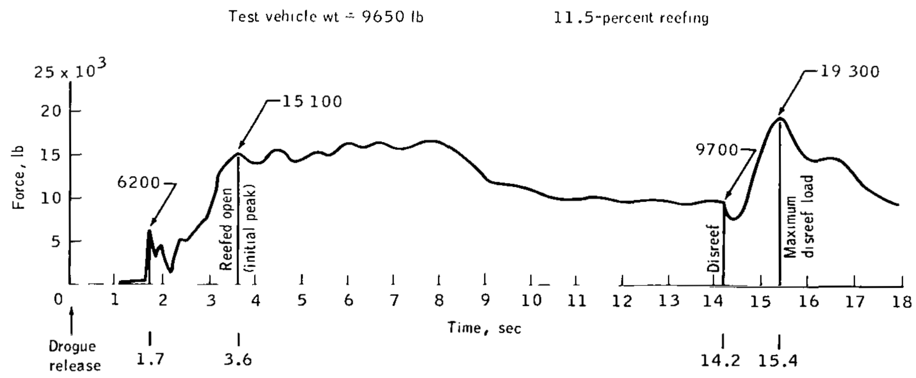


Figure 9. - Main parachute force-time history, test 6, MSC (124.5-foot-D_O canopy).

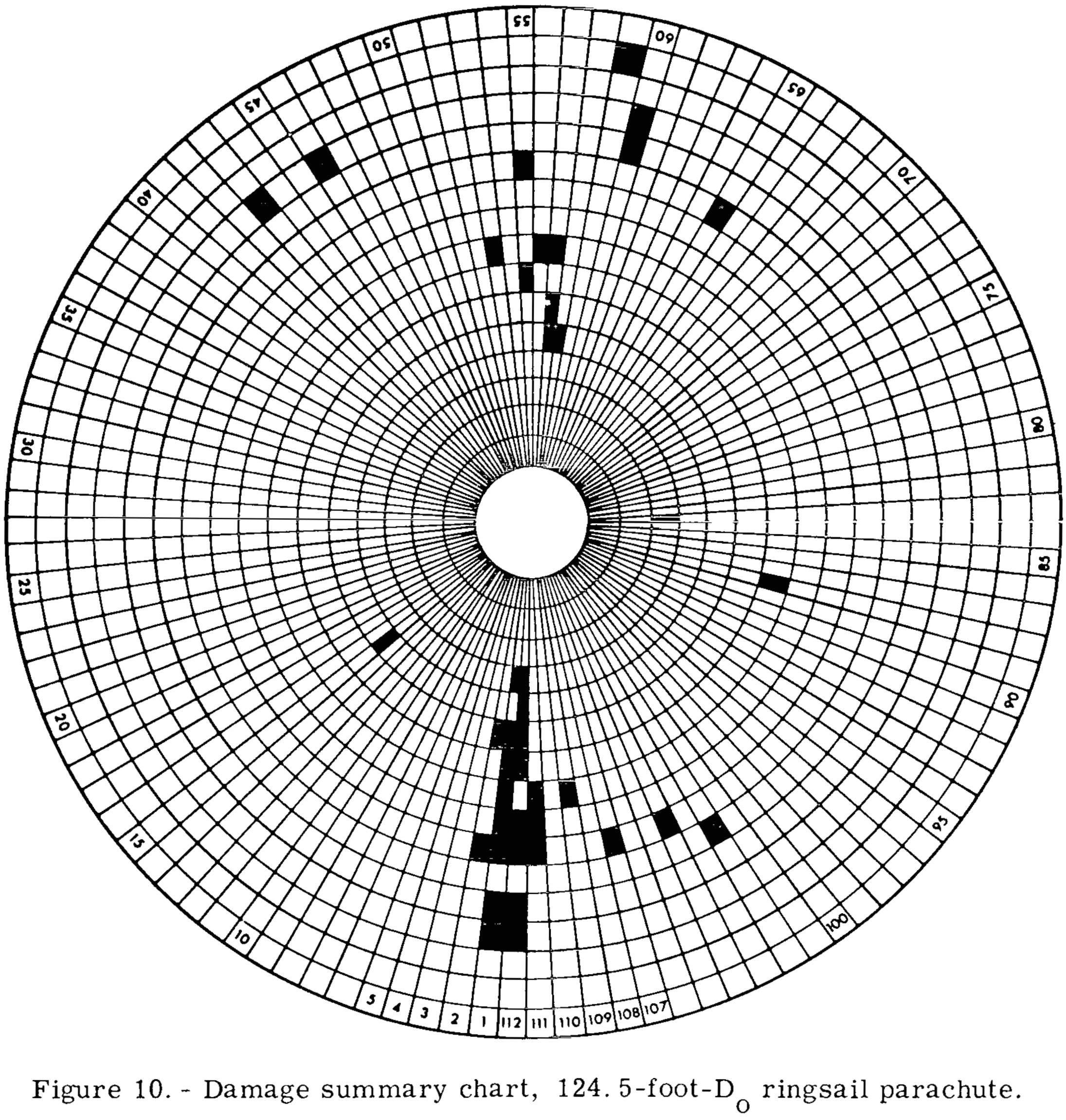


Figure 10. - Damage summary chart, 124.5-foot-D_o ringsail parachute.

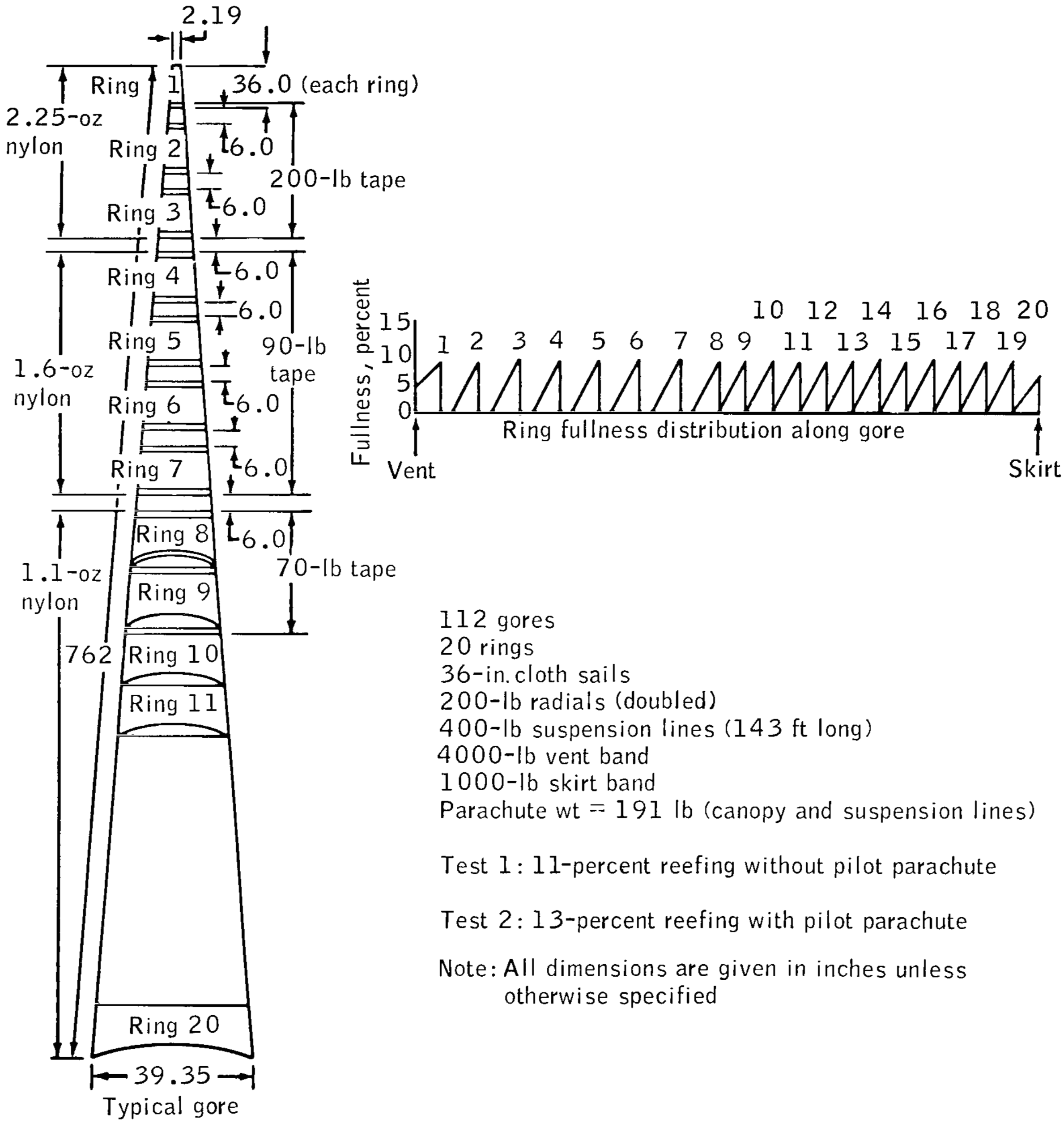
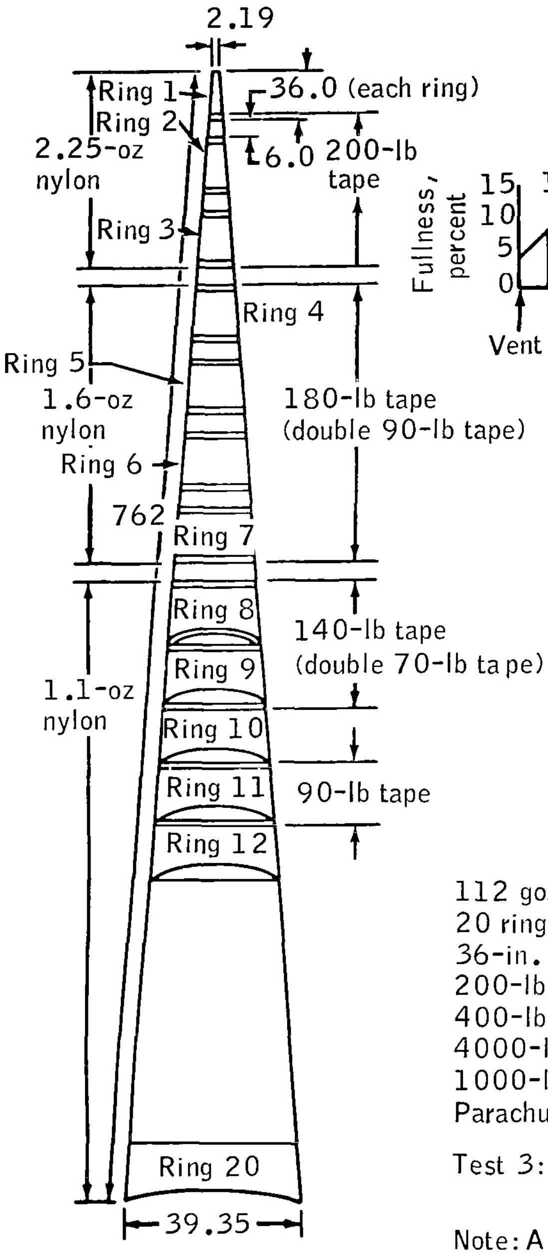
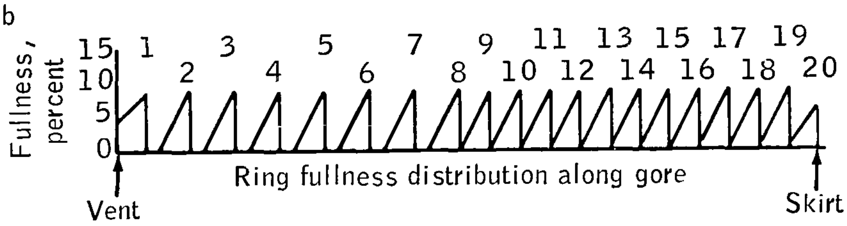


Figure 11. - Original design configuration, 127.0-foot-D_o ringsail parachute.



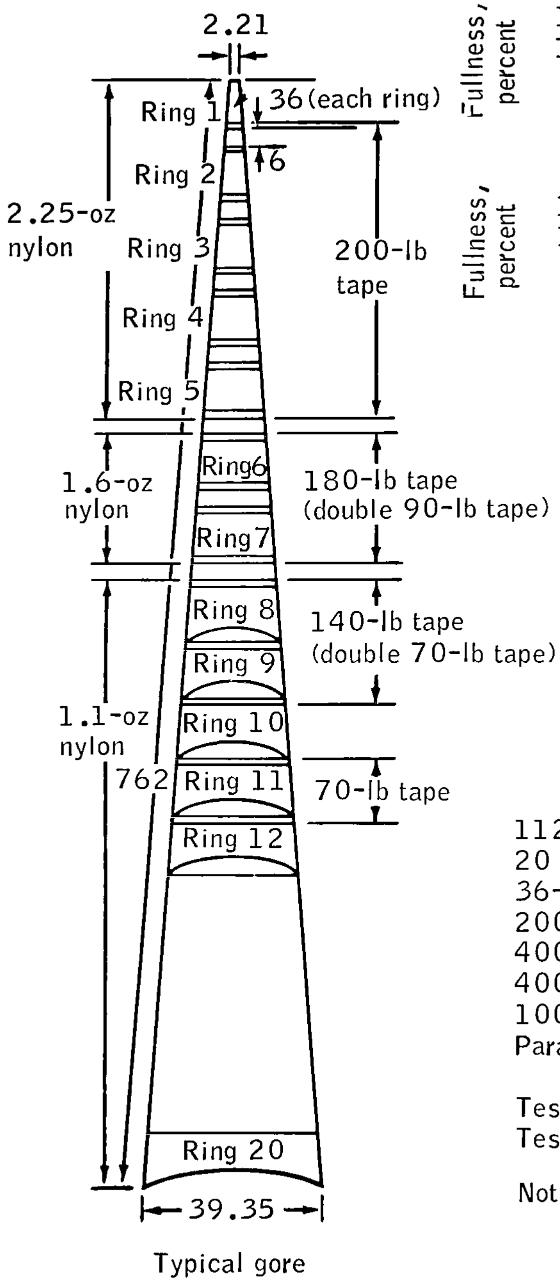


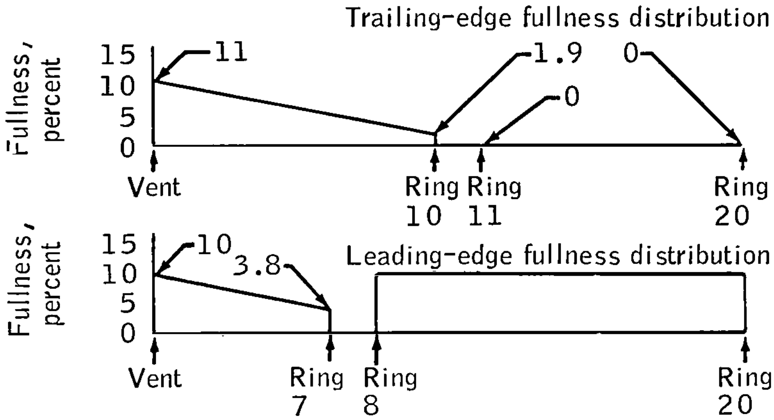
112 gores
20 rings
36-in. cloth sails
200-lb radials (doubled)
400-lb suspension lines (143 ft long)
4000-lb vent band
1000-lb skirt band
Parachute wt = 197 lb (canopy and suspension lines)

Test 3: 16-percent reefing

Note: All dimensions are given in inches unless otherwise specified

Figure 12. - First modification, 127.0-foot-D_o ringsail parachute.





112 gores
20 rings
36-in. cloth sails
200-lb radials (doubled)
400-lb suspension lines (143 ft long)
4000-lb vent band
1000-lb skirt band
Parachute wt = 195.7 lb (canopy and suspension lines)

Test 4: 16-percent reefing (separated pilot parachute)
Test 5: 16-percent reefing

Note: All dimensions are given in inches unless otherwise specified

Figure 13. - Second modification, 127.0-foot-D_o ringsail parachute.

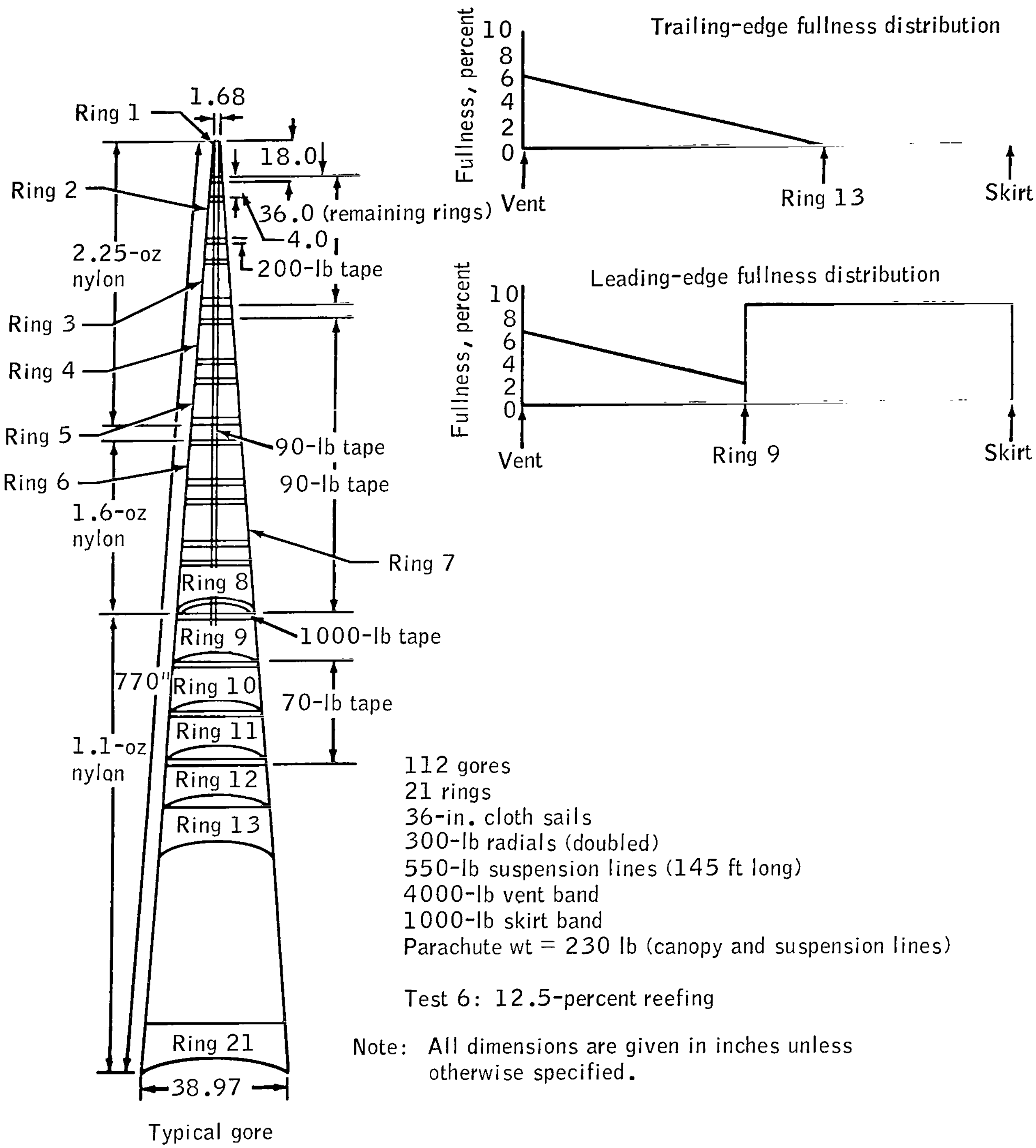
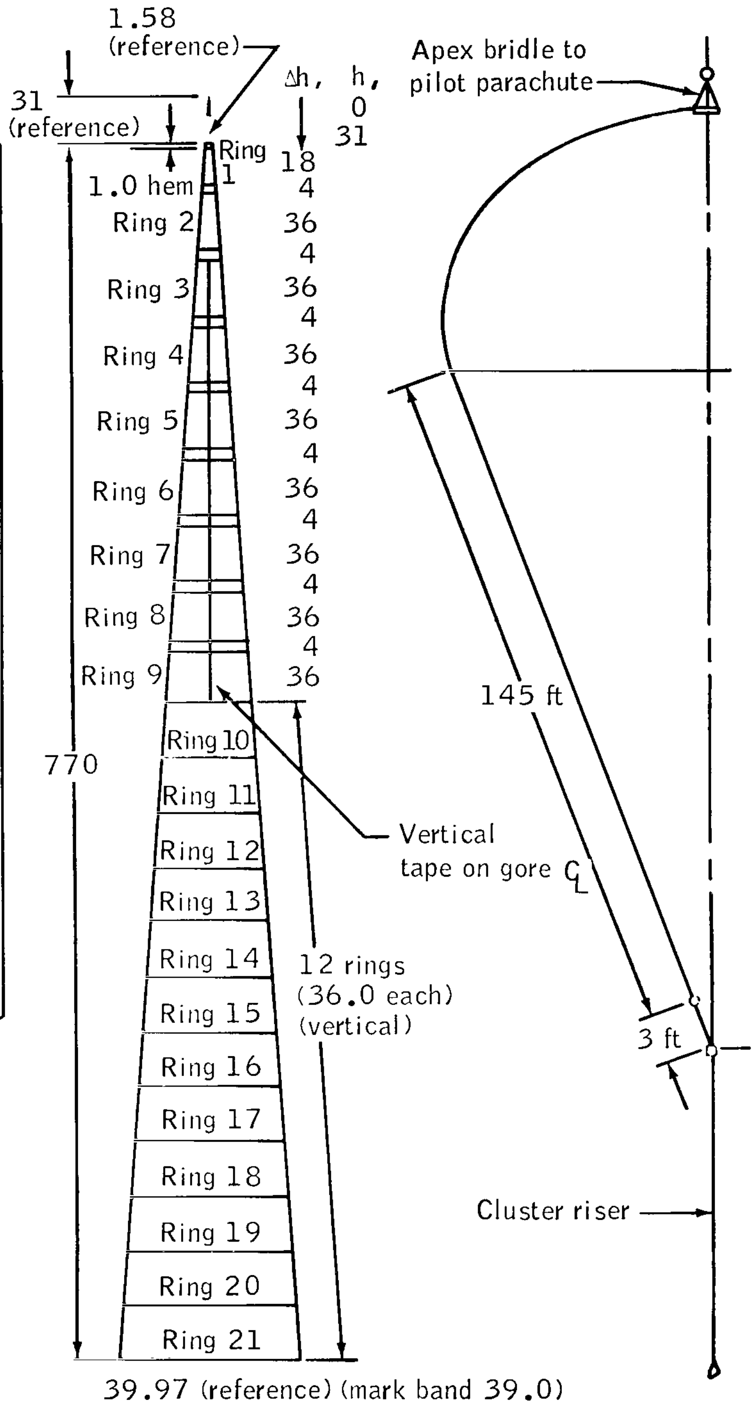


Figure 14. - Original configuration, 128.8-foot-D_o ringsail parachute.

Sail pattern dimensions (including 1.60-in. seam allowance; 112 gores)

Sail	h ± 0.5 in.	A, in.	B, in.
1	20.5	3.26	4.40
2	36.5	4.62	6.65
3	36.5	6.87	8.87
4	36.5	9.09	11.05
5	36.5	11.27	13.19
6	36.5	13.40	15.29
7	36.5	15.49	17.33
8	36.5	17.53	19.32
9	36.5	19.51	22.53
10	36.5	21.25	24.42
11	36.5	22.93	26.27
12	36.5	24.55	28.08
13	36.5	26.13	29.84
14	36.5	27.74	31.54
15	36.5	29.33	33.20
16	36.5	30.86	34.80
17	36.5	32.34	36.34
18	36.5	33.76	37.81
19	36.5	35.13	39.22
20	36.5	36.44	40.57
21	36.5	37.68	40.57



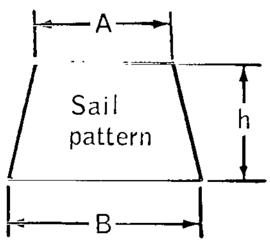


Figure 15. - Gore pattern, 128.8-foot-D_o ringsail parachute.

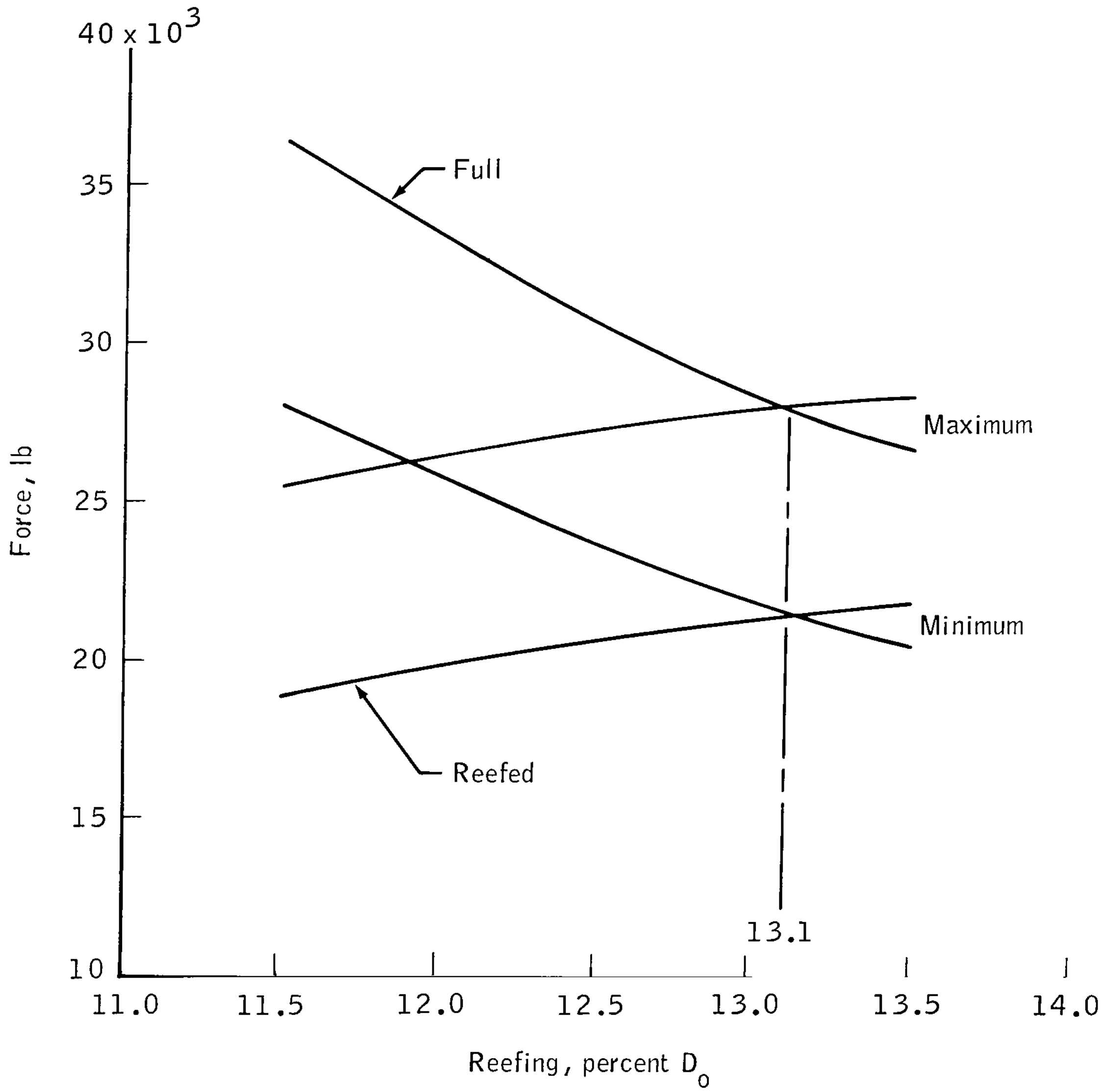


Figure 16. - Opening force plotted against reefing ratio — 128.8-foot-D_0 ringsail parachute.

APPENDIX A

DESIGN FACTORS

Stress in a parachute structure is defined in terms of unit loads appropriate to each member rather than in terms of the load per unit of cross-section area. The following unit loads are used in the present analysis:

Cloth or fabric stress . . . . lb/in.

Lines, tapes, and webs . . . . . . lb/member

The allowable strength of parachute textiles is defined as

$$P_A = A_P P_r \tag{A1}$$

or

$$P_Z = A P_r \tag{A2}$$

The design factor for a given member is established by

$$D.F. = \frac{S.F.}{A_P} \tag{A3}$$

where S. F. = design safety factor = ultimate load/limit load. The values assigned to the factors involved in equations (A1) to (A3) were the same throughout the Century series investigation and are reproduced for reference in table A-I.

TABLE A-I. - CANOPY DESIGN FACTORS

Factor	Canopy cloth	Suspension lines	Risers
S. F.	1.50	1.50	2.00
u	.95	.95	.95
e	.95	.95	.95
o	1.00	1.00	1.00
k	1.00	1.00	1.00
γ	.92	.97	.98
l	1.00	1.00	1.00
s	.95	.95	.95
cos ϕ	1.00	.95	.95
A_P	.79	.79	.80
D. F.	1.90	1.90	2.50

APPENDIX B

EL CENTRO TESTS

THE 127.0-FOOT-D_o RINGSAIL PARACHUTE TESTS

Test 1

Purpose. - After the six preliminary drop tests of the 124.5-foot-D_o parachute at MSC, the canopy configuration was modified to a 127.0-foot-D_o biconical design; and the test operation was transferred to the Joint Parachute Test Facility, El Centro, California, where a data-oriented drop-test program was initiated. The purpose of the first test at the El Centro facility was to evaluate the inflation characteristics of the new design and to provide real data related to the selected reefing parameters.

Test configuration. - The parachute configuration (127.0-foot-D_o biconical ringsail) is shown in figure B-1 and featured 11-percent skirt reefing for an 8-second period. The test vehicle was a 9500-pound U.S. Air Force-furnished T-10 weight bomb.

Results. - Generally, deployment of the parachute was satisfactory. During the initial filling process, the vent was slightly displaced to one side of the parachute center line. The canopy also failed to develop the large, bulbous reefed shape that was characteristic of the 124.5-foot-D_o parachute. Approximately 2.5 seconds after disreefing and at a load of 23 650 pounds, a rip appeared in ring 6 of gore 20. This rip was progressive in nature and spread quickly toward the vent and skirt bands. The vent and skirt bands did not fail, and the parachute remained inflated during descent. Figure B-2 presents the parachute loads during the inflation process, and figure B-3 is a photograph showing the inflated canopy with the split gore.

Conclusions. - The dynamic pressure at disreefing was approximately 23 psf. This high pressure caused the canopy damage and was attributed to the failure of the canopy to develop sufficient drag area during the reefed stage in order to decelerate the test system adequately. It was postulated that the 11-percent reefing ratio, combined with the high canopy porosity, was such that equilibrium flow conditions occurred early during inflation, and the canopy did not continue to grow or expand as had been anticipated.

Test 2

Purpose. - The purpose of test 2 was to evaluate the inflation characteristics of the 127.0-foot-D_o ringsail parachute with the reefing ratio increased to 13 percent and with a pilot parachute attached to the canopy apex in an attempt to stabilize the vent and crown area during deployment and inflation.

Test configuration. - The parachute configuration is shown in figure B-4 and featured 13-percent skirt reefing for an 8-second period. The test vehicle was the 9500-pound T-10 weight bomb.

Results. - Deployment and inflation appeared to be satisfactory, except for the lack of canopy growth during the reefed stage. Approximately 3.5 seconds after disreefing and at a load of 20 600 pounds, the parachute developed a rip similar to that seen in test 1. During test 2, the damage began at ring 5 of gore 41. The dynamic pressure at disreefing was again high, and this high dynamic pressure was attributed to the lack of canopy growth during the reefed stage.

Conclusions. - The canopy damage was caused by the high loading that resulted when the canopy disreefed at a higher-than-planned dynamic pressure. It was hoped, however, that the general reefed shape could be maintained in succeeding tests so that cluster-interference problems could be evaluated and compared with problems of the smaller ringsail parachute designs.

Test 3

Purpose. - Because test 2 indicated structural inadequacy in the crown area and a continued lack of reefed canopy growth, two modifications were incorporated prior to test 3. The skirt reefing was increased to 16 percent, and the crown area was structurally reinforced by the incorporation of 2.25-ounce nylon material and by doubling the strength of the panel leading- and trailing-edge tapes. Test 3 was conducted to evaluate the inflation characteristics of the 127.0-foot-D_o ringsail parachute with the two modifications.

Test configuration. - The parachute configuration is shown in figure B-5 and features 16-percent skirt reefing for an 8-second period. The test vehicle was the 9500-pound T-10 weight bomb.

Results. - Deployment and inflation were normal, with the canopy developing a large, bulbous shape during the reefed stage. A failure, similar to that of the previous two tests, occurred approximately 0.8 second following disreefing. The rip began at ring 5 of gore 33 at a load of 19 375 pounds. Figure B-6 presents the canopy-load history throughout the deployment and inflation process. Review of the test films indicated that an area of stress concentration existed along the trailing edge of each sail because of a lack of fullness.

Conclusions. - A comparison of figures B-2 and B-6 indicated that the dynamic pressure at disreefing was substantially reduced from that of previous tests. This fact, combined with the observed growth of the reefed canopy, indicated that the 16-percent reefing ratio drastically altered the filling characteristics of the parachute. There was more inflow of air into the canopy than could be dissipated through the crown slots, and the canopy was thereby forced into a larger inflated reefed shape with higher drag.

Because minor structural modification (fig. 12 of the text) proved ineffective in stopping or limiting the extent of canopy damage, a thorough review of the structural design was made. The analysis assumed the load to be distributed evenly throughout the canopy and indicated a unit loading below the actual tested strength of the material used in the critical area of the canopy. Obviously, the assumption that the total load was distributed evenly within the canopy was not valid because of the unsymmetrical shape of the inflating parachute and because failures had occurred. However, no analysis existed that could account for local conditions within the canopy. The stress-concentration area indicated by the film analysis and the unpredictable local load conditions during inflation prompted a change in the canopy fullness for subsequent tests (fig. 13 of the text).

Test 4

Purpose. - The purpose of test 4 was to evaluate the new configuration that incorporated the new fullness distribution and additional structural reinforcement.

Test configuration. - The parachute configuration is shown in figure B-5. The parachute reefing ratio was 16 percent. The 9500-pound T-10 weight bomb was used.

Results. - Shortly after line stretch, the pilot parachute separated from the canopy, and the failed pilot riser rebounded into the canopy, totally destroying the parachute.

Conclusions. - No conclusions as to the performance of the modified canopy could be drawn because of the early failure caused by the pilot riser. The pilot parachute and riser were not recovered; therefore, it could only be speculated that the connector link between the pilot parachute riser and the main parachute apex bridle was structurally weak.

Test 5

Purpose. - Test 5 was a repeat of test 4. The only change made was the incorporation of a stronger connector link between the pilot parachute riser and the main parachute apex bridle.

Test configuration. - The configuration for test 5 was identical with that of test 4 and is shown in figure B-5.

Results. - Deployment and initial inflation of the parachute appeared normal and satisfactory. Approximately 1.0 second after disreefing and at a load of 21 950 pounds, a rip appeared in ring 7 of gore 90. As in previous tests, the rip was progressive in nature and spread quickly to the vent and skirt bands. However, the parachute remained inflated and satisfactorily recovered the test vehicle.

Conclusions. - Analysis of the deployment loads, as in previous tests, revealed no new information to aid in solution of the parachute structural problem. Therefore, the decision was made at this time to abandon the biconical design and to return to an ogival configuration because the ogival design (124.5-foot D_o) had not shown a tendency to be sensitive to local conditions.

THE 128.8-FOOT-D_O RINGSAIL PARACHUTE TESTS

Test 6

Purpose. - Analysis of the failures encountered during testing of the 127.0-foot-D_O biconical design indicated that the reduction in fullness and structural capability from that of the 124.5-foot-D_O canopy was far too severe, contrary to the best available stress analysis. The program decision was made to return to a configuration nearer the original design (124.5-foot D_O) and to incorporate only a slight reduction in fullness and essentially no reduction in structural capability for the heavyweight canopy. The purpose of test 6 was to evaluate the inflation performance of the 128.8-foot-D_O canopy and to evaluate the effectiveness of the selected fullness distribution.

Test configuration. - The parachute design is shown in figures 14 (of the text) and B-5, and the material selection is contained in table IV where this canopy is identified as the heavyweight version. The reefing ratio was 16 percent. The T-10 weight bomb was increased to 9750 pounds.

Results. - Deployment and inflation were satisfactory, with the parachute assuming a large, bulbous, inflated shape during the reefed stage. Disreefing and full inflation occurred in a normal fashion. Figure B-7 is a photograph of the parachute during descent. The force-time history (fig. B-8) shows close agreement between the maximum reefed load (25 650 pounds) and disreefed load (24 775 pounds), thus indicating a proper selection of reefing parameters. Figure B-9 is a plot of parachute oscillation angle as a function of time. This figure shows that the parachute exhibited a maximum oscillation of 12.5° and had an oscillation period of approximately 14 seconds. Figure B-10 presents the descent rate as a function of time for the test system. The test system appeared to have achieved steady-state descent conditions approximately 27 seconds following launch. By averaging 46 data points obtained at 1-second intervals between $T = 27$ seconds and $T = 73$ seconds, a velocity of 26.4 fps was obtained. Substituting this average descent rate into the equation

$$C_D S = \frac{W_T}{\frac{1}{2}\rho V^2} \tag{B1}$$

(given a parachute drag area of 11 800 ft^2) and dividing the ratio by the total canopy area (13 035 ft^2) indicates that the parachute had a drag coefficient of 0.9.

Conclusions. - Test 6 was successful and indicated that the inflation process on the 128.8-foot-D_O canopy was similar in nature and appearance to that of smaller ringsail parachutes. The absence of damage indicated ample structural load capability.

Test 7

Purpose. - Test 7 employed a lightweight version of the 128.8-foot-D_o ringsail parachute and was designed to subject the lightweight canopy to dynamic conditions identical with those to which the heavyweight version was subjected (test 6).

Test configuration. - The parachute configuration is shown in figures B-5 and B-11, and the canopy material selection is contained in table IV. (In table IV, this canopy is identified as the lightweight version.) The 9750-pound T-10 weight bomb was used.

Results. - Deployment and inflation appeared normal and satisfactory until the parachute reached its full-open state. When the parachute reached the full-open state, a tear appeared in rings 5 and 6 of gore 3. This damage spread upward to the vent band and downward to the top of ring 9, where it was stopped by the 1000-pound tape. At that time, another rip began in gore 1 at the top of ring 9 and continued downward to the skirt band. The 1000-pound circumferential tape at the top of ring 9 appeared to have been effective in stopping the rip in gore 3. The tape did not break, and the canopy did not open as widely as in previous tests with canopies having split gores.

The force-time history (fig. B-12) showed close agreement between the maximum reefed and disreefed loads (26 800 and 24 200 pounds, respectively). There also appeared to be close agreement between the deployment loads on this test and test 6. The maximum reefed loads on tests 6 and 7 were 25 650 and 26 800 pounds, respectively. The maximum disreefed loads on tests 6 and 7 were 24 775 and 24 200 pounds, respectively.

Figure B-13 presents descent rate as a function of time for test 7. By averaging 41 data points from $T = 50$ seconds to $T = 90$ seconds, a velocity of 27.6 fps was obtained. Substitution of this average velocity into equation (B1) provides a parachute drag coefficient of 0.83. The high descent rate and low drag coefficient for test 7 probably result from the increased porosity because of the canopy damage.

Conclusions. - The major difference between the parachute used during test 7 and the parachute used during test 6 was a slight weight reduction (approximately 25 pounds), which was a result of material changes in the canopy. (See figs. 14 (of the text) and B-11.) It appeared feasible that the change from 2.25-ounce material (90 lb/in. breaking strength) in ring 5 may have created a condition of overstress during deployment and, therefore, triggered the failure mechanism. However, current analytical methods did not show this to be the situation.

Test 8

Purpose. - Test 8 was conducted to investigate the inflation characteristics of the large-diameter ringsail parachutes when employed in a cluster. For this test, the parachute used during test 6 was combined with a newly manufactured parachute of the same design (128.8-foot-D_o heavyweight version).

Test configuration. - The test configuration is shown in figure B-14. The identical parachute systems are shown in figures 14 (of the text) and B-5, and the canopy material selection is listed in table IV. Each of the two parachutes was reefed to 13 percent for 8 seconds. The T-10 weight bomb was ballasted to 17 000 pounds.

Results. - Deployment of the parachutes was satisfactory, with aerodynamic blanketing of one parachute occurring during the reefed stage. An indication of the degree of blanketing can be obtained from the force-time history of test 8 (fig. B-15) by comparing the individual parachute loads. The total load measurement shows close agreement between maximum reefed and disreefed loads (39 000 and 39 500 pounds, respectively), indicating that the 13-percent reefing ratio was probably a good choice.

Figure B-16 presents descent rate as a function of time for the cluster configuration. By averaging 51 data points from $T = 40$ seconds to $T = 90$ seconds, a velocity of 26 fps was obtained. Use of this descent rate in equation (B1) (with a total system weight of 17 720 pounds) provides an effective drag area of 22 000 ft^2. Comparing this area with the total canopy area of two 128.8-foot-D_o ringsail parachutes (13 035 ft^2 each) provides a drag coefficient for the clustered configuration of 0.85. Data obtained during the Apollo parachute drop-test program indicate that the drag coefficient of a single ringsail parachute when used in a two-parachute cluster is degraded by approximately 5 percent. If it is assumed that the same holds true for the 128.8-foot-D_o ringsail parachute, a single-parachute drag coefficient of 0.89 would be indicated, which compares favorably with the drag coefficient obtained from test 6. Figure B-17 shows the two-parachute-cluster system during descent.

Conclusions. - This test was considered to be a successful demonstration of cluster operation of Century series ringsail parachutes and indicated the feasibility of this approach for large-payload recovery. The aerodynamic blanketing situation encountered during inflation was similar to the situation encountered with the 83.5-foot-D_o ringsail parachute during the Apollo ELS development. This problem was solved for the Apollo parachute system by the incorporation of an open slot in ring 5 of each of the three parachutes.

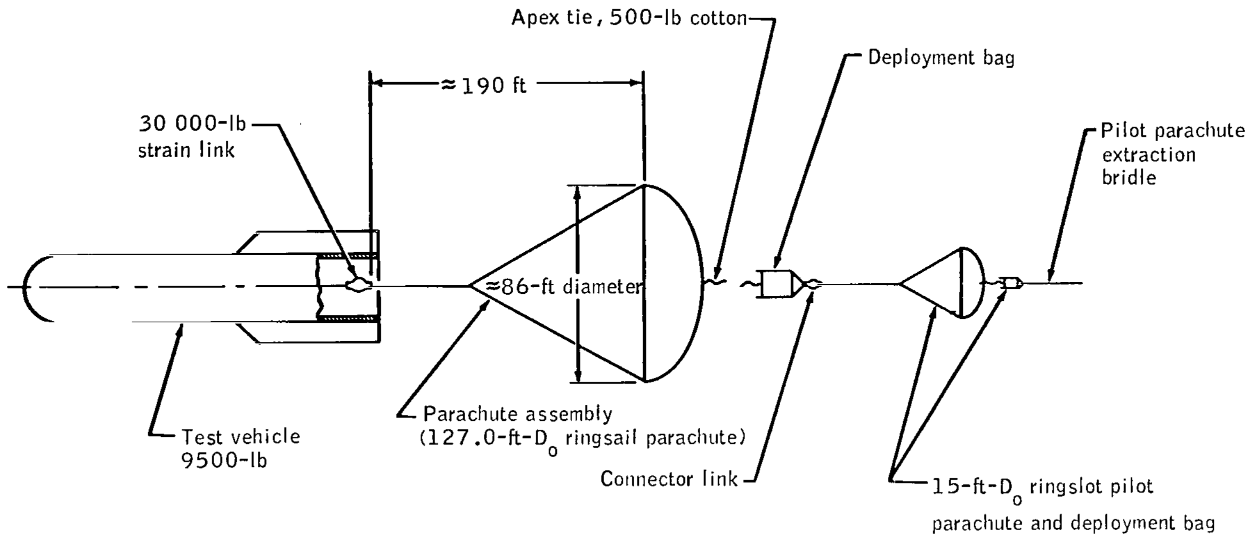


Figure B-1. - Test 1, 127.0-foot-D_o single ringsail parachute.

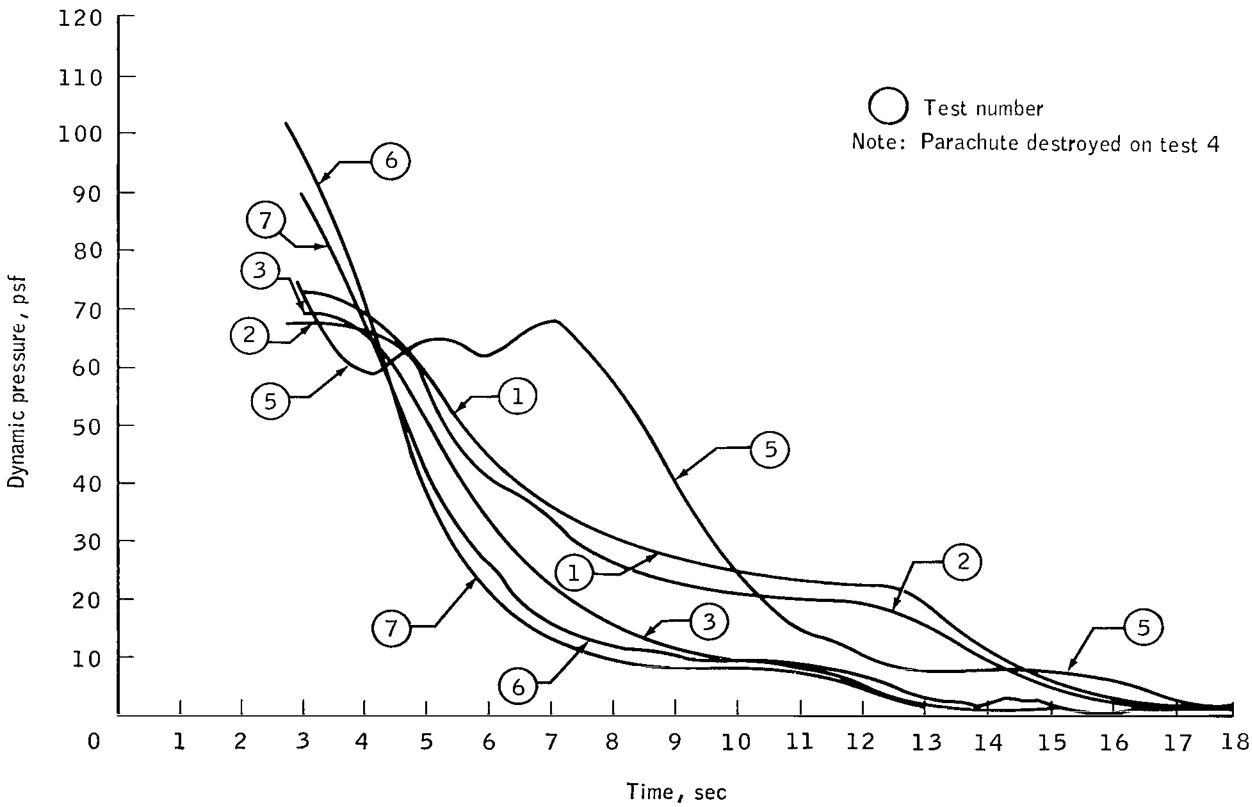


Figure B-2. - Dynamic pressure plotted against time, single ringsail parachute.

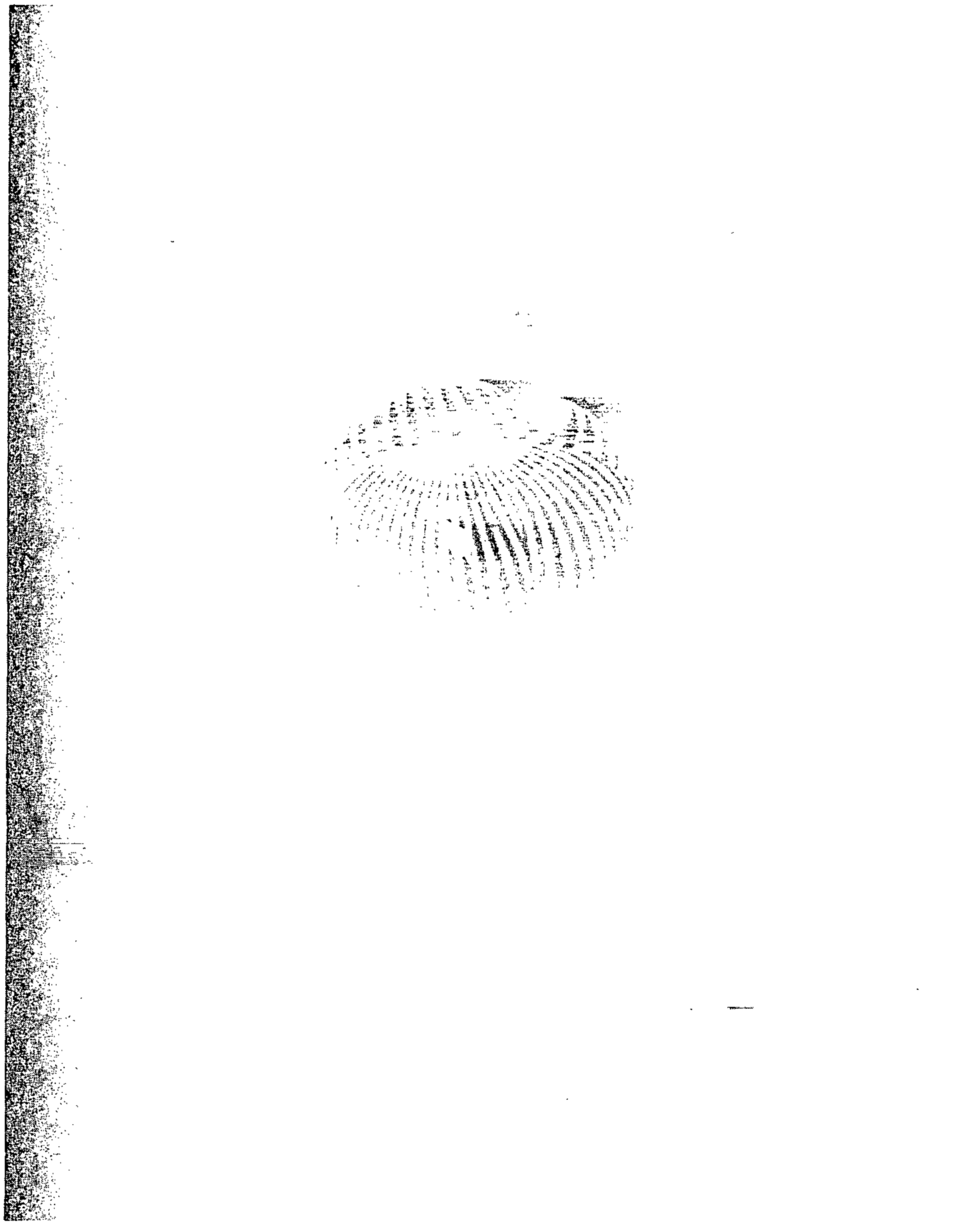


Figure B-3. - Inflated canopy showing split gore.

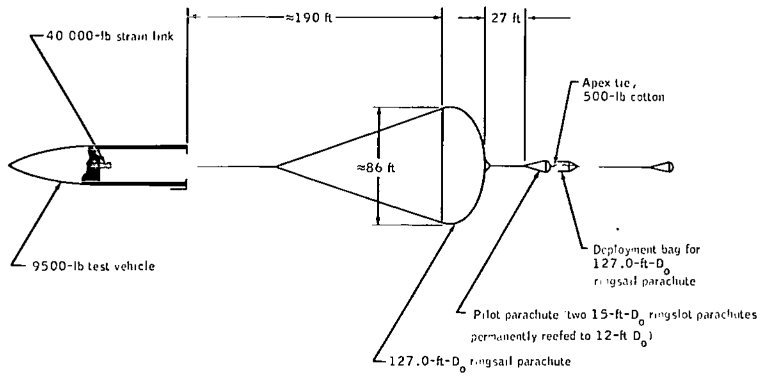


Figure B-4. - Test 2, 127.0-foot-D$_o$ single ringsail parachute.

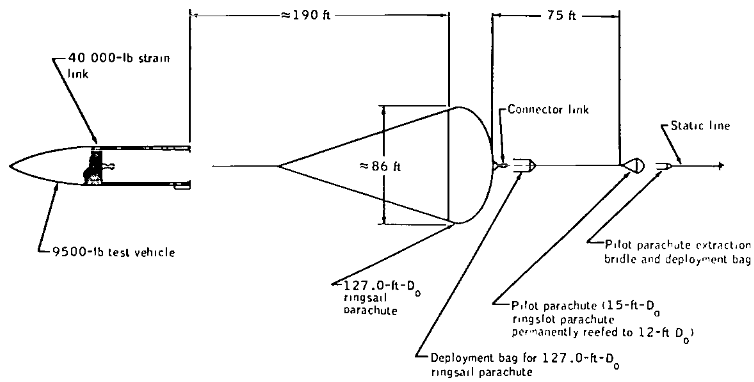


Figure B-5. - Tests 3 to 5, 127.0-foot-D$_o$ ringsail parachute; tests 6 and 7, 128.8-foot-D$_o$ ringsail parachute.

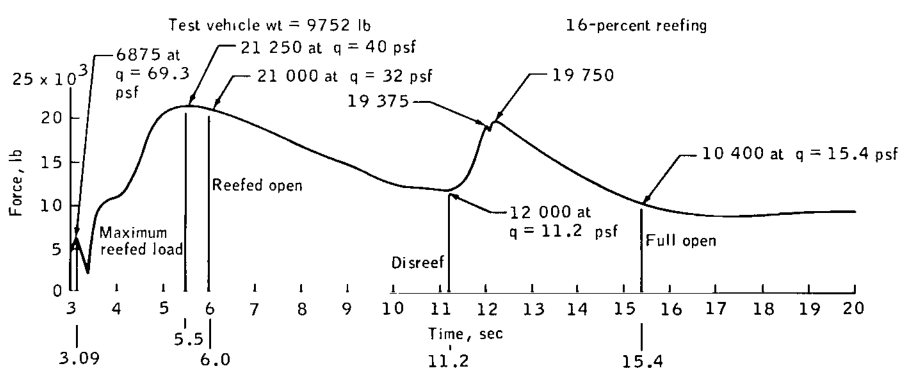


Figure B-6. - Main parachute force-time history, test 3, 127.0-foot-D$_o$ ringsail parachute.

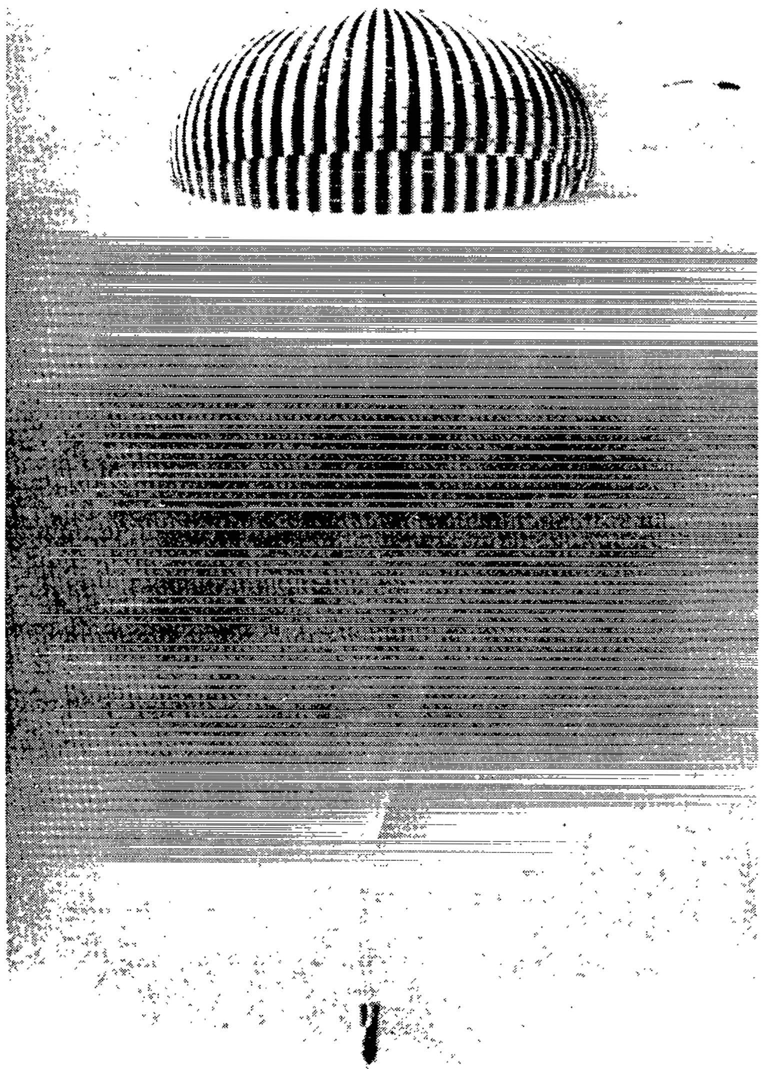


Figure B-7. - The 128.8-foot-D_o ringsail parachute fully inflated.

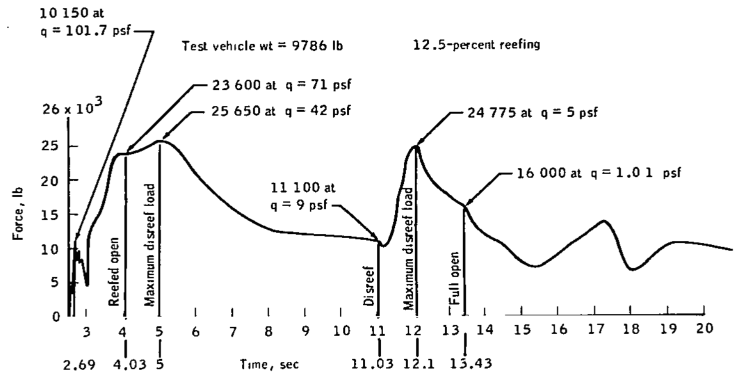


Figure B-8. - Main parachute force-time history, test 6, 128.8-foot-D_o ringsail parachute.

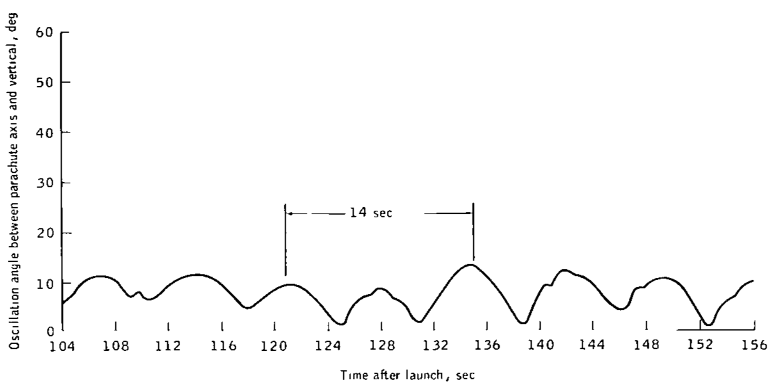


Figure B-9. - Oscillation angle plotted against time, test 6.

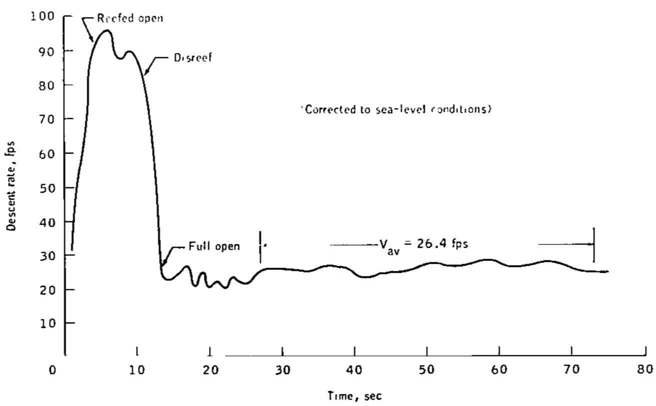


Figure B-10. - Single-parachute descent rate, test 6.

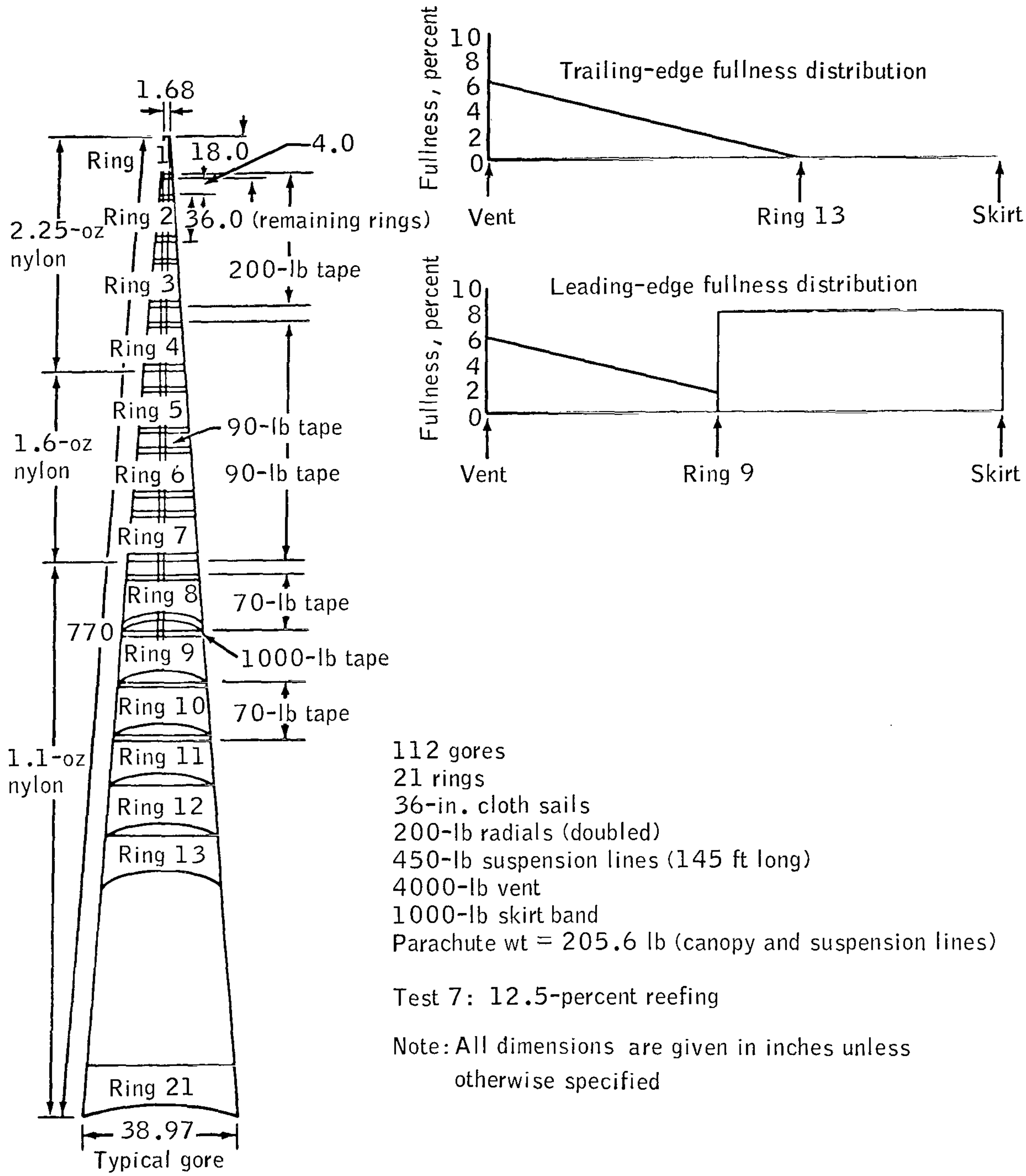


Figure B-11. - First modification, 128.8-foot-D_o ringsail parachute.

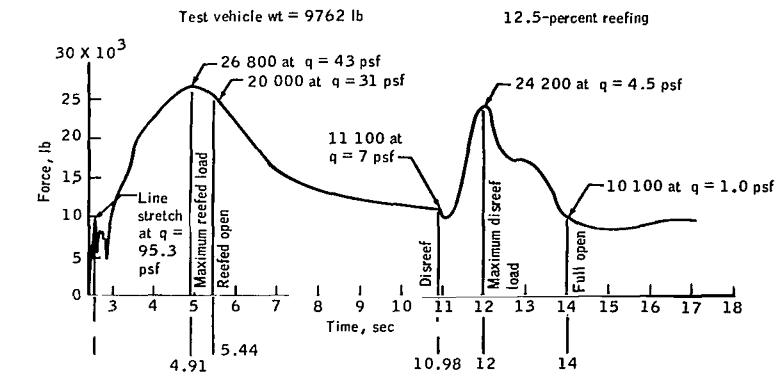


Figure B-12. - Main parachute force-time history, test 7, 128.8-foot-D_o ringsail parachute.

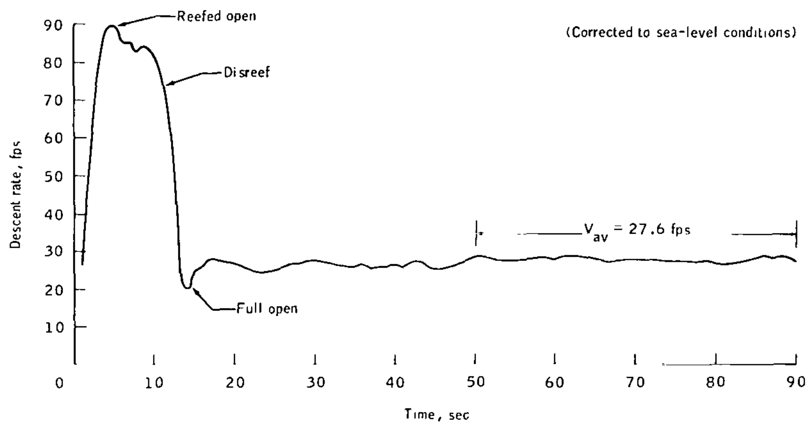


Figure B-13. - Single-parachute descent rate, test 7.

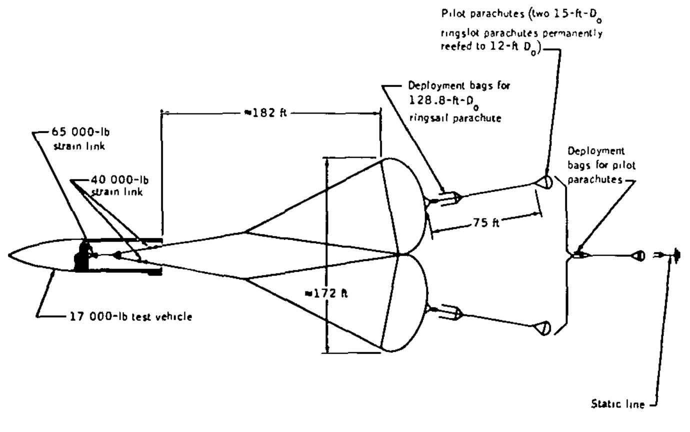


Figure B-14. - Test 8, 128.8-foot-D_o, two-ringsail-parachute cluster.

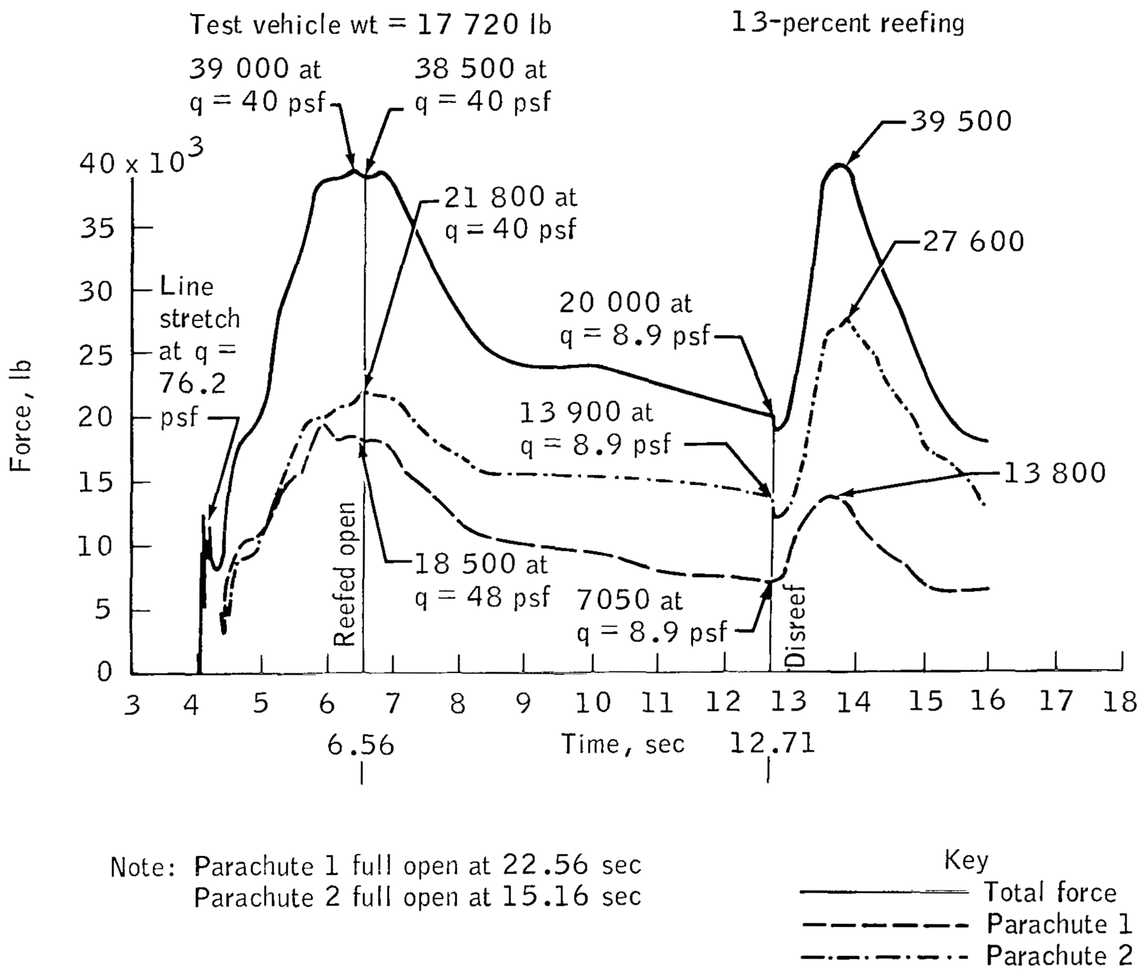


Figure B-15. - Main parachute force-time history, test 8, 128.8-foot-D_o ringsail parachute cluster.

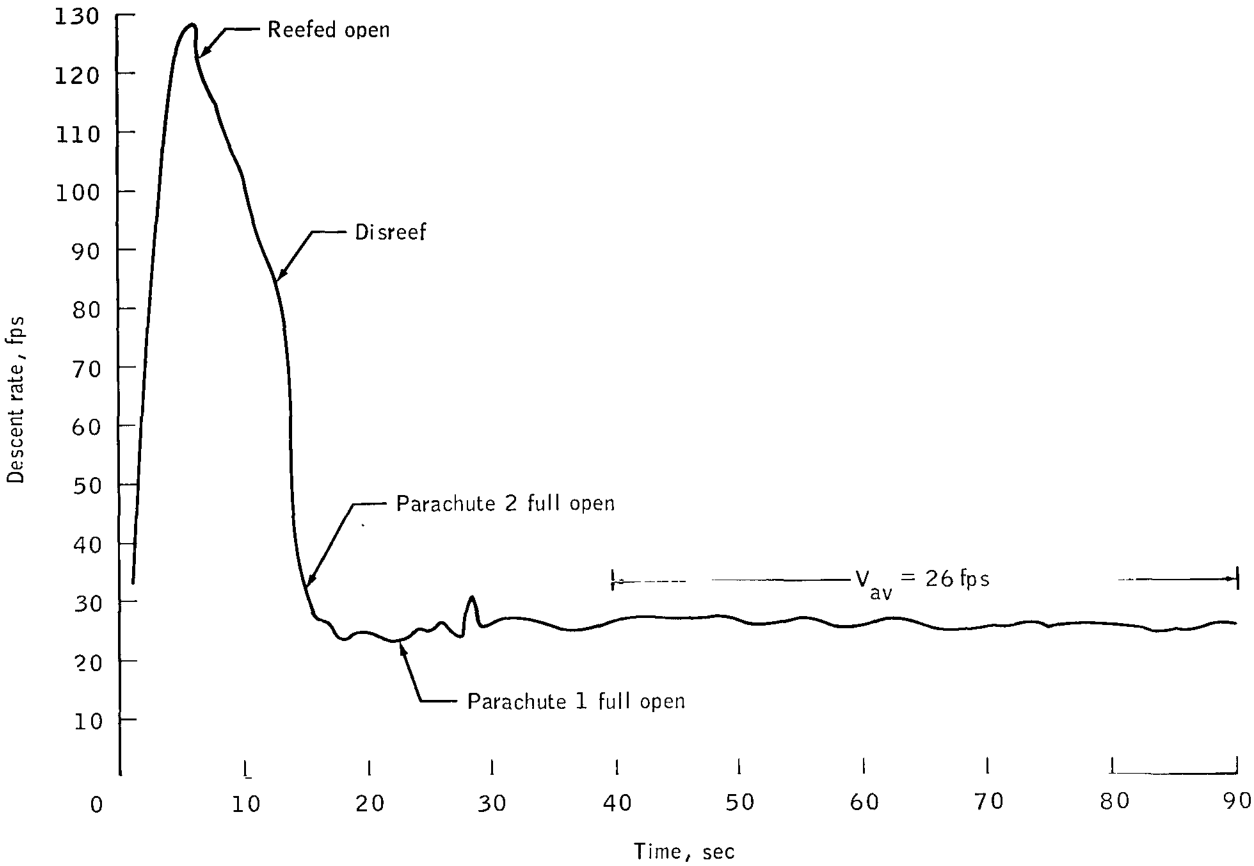


Figure B-16. - Cluster descent rate, test 8.

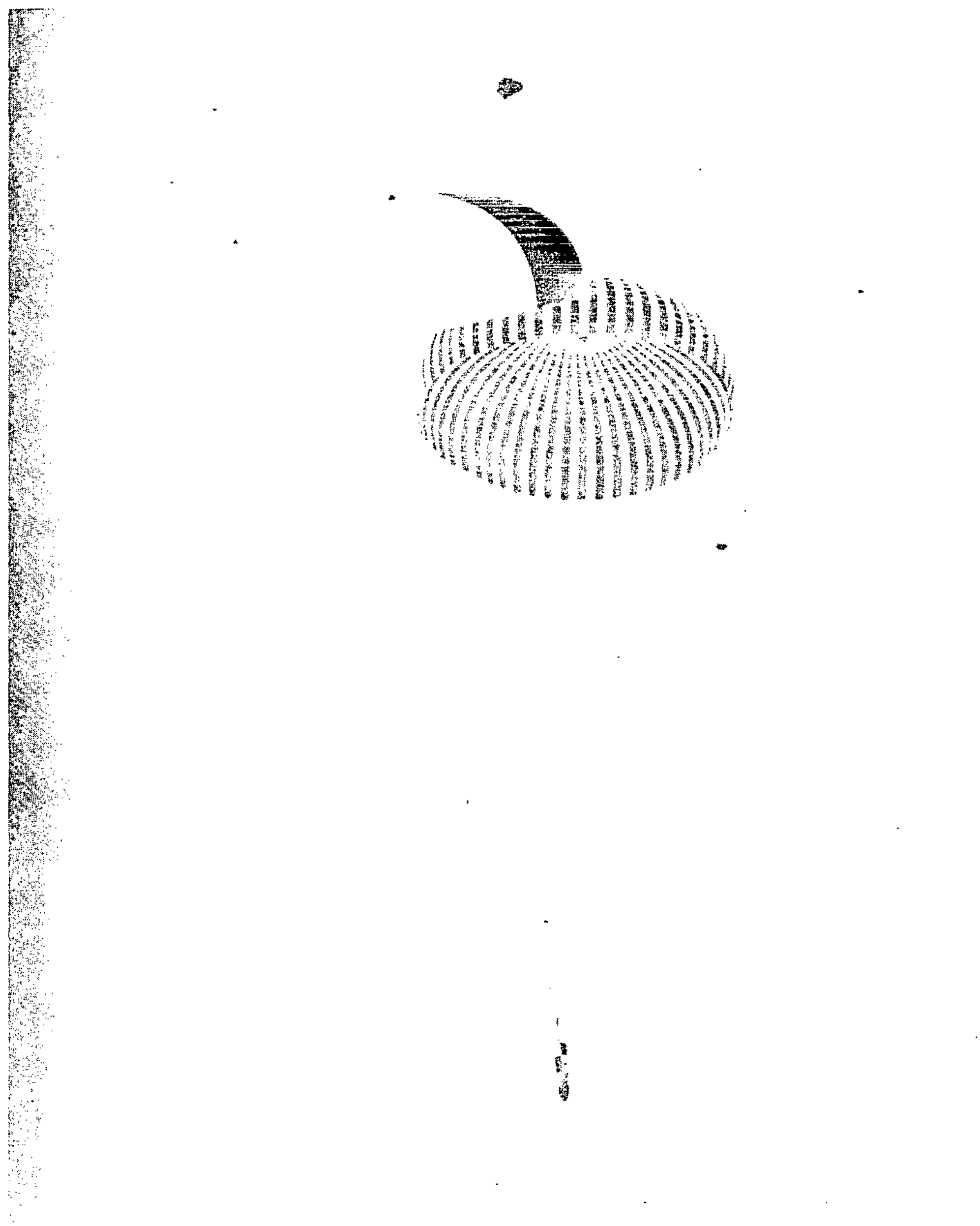


Figure B-17. - Cluster test, 128.8-foot-D_o ringsail parachutes, El Centro, California.

APPENDIX C

APPARATUS

TEST VEHICLES

The MSC Test Range

Testing of the 124.5-foot-D_o ringsail parachute at the MSC test range was performed by using a modified sled-type test vehicle 14 feet long and 80 inches wide. The box frame (15-inch welded channels) was covered on one side with 5/16-inch-thick steel plate to provide a smooth surface for extracting the test vehicle from the aircraft. The test vehicle had three compartments: a forward compartment covered with aluminum to provide a platform for mounting the main parachute, riser, and load link; a middle compartment used for instrumentation and sequencer storage; and an aft compartment containing ballast (fig. C-1). The releases for the drogue and main parachutes (pyrotechnically operated disconnects) were mounted along the front of the test vehicle. The test vehicle was equipped with an "extre" bar supplied by the U.S. Air Force for extracting the test vehicle from the aircraft.

The El Centro, California, Test Range

Testing of the 127.0- and 128.8-foot-D_o ringsail parachutes was accomplished at the El Centro, California, facilities. An Air Force-furnished T-10 weight bomb was used as the test vehicle and was equipped with complete instrumentation.

INSTRUMENTATION

The 124.5-Foot-D_o Ringsail Parachute

All tests of the 124.5-foot-D_o ringsail parachute were conducted at the MSC test facilities. Deployment forces, measured by a strain link, were recorded with a light-beam oscillograph. An accelerometer was mounted on the longitudinal axis to provide indications of parachute deployment loads, should damage occur to the strain link. All attempts (using a pitot tube attached to the aft section of the test vehicle) to measure dynamic pressure during parachute deployment failed. A pyrotechnic sequencer system was used to program the release of the drogue parachute following vehicle extraction and free fall and to jettison the main parachute at ground impact.

The 127.0- and 128.8-Foot-D_o Ringsail Parachutes

All tests of the 127.0- and the 128.8-foot-D_o parachutes were conducted at the El Centro, California, facilities, where complete instrumentation facilities exist. Figure C-2 shows the data flow diagram of the instrumentation employed at the El Centro facilities.

PHOTOGRAPHY

The MSC Tests

Color motion pictures were taken throughout all tests. Two 16-millimeter cameras were mounted on the forward portion of the test vehicle, two were on the drop aircraft, and a minimum of two cameras was operated from the ground. (The entire test sequence was recorded.) Additional cameras, mounted on the chase aircraft, obtained pictures of test vehicle extraction, parachute deployment, and the inflation process.

The El Centro Tests

Photographic support varied throughout the test program but in general conformed to the following: One camera was mounted on the test vehicle to record parachute deployment and inflation; a minimum of two ground-operated cameras recorded the entire test sequence; one camera was placed on board the drop aircraft to photograph release of the test vehicle from the aircraft; and one camera was employed on board the chase aircraft to photograph test vehicle release, parachute deployment, and inflation.

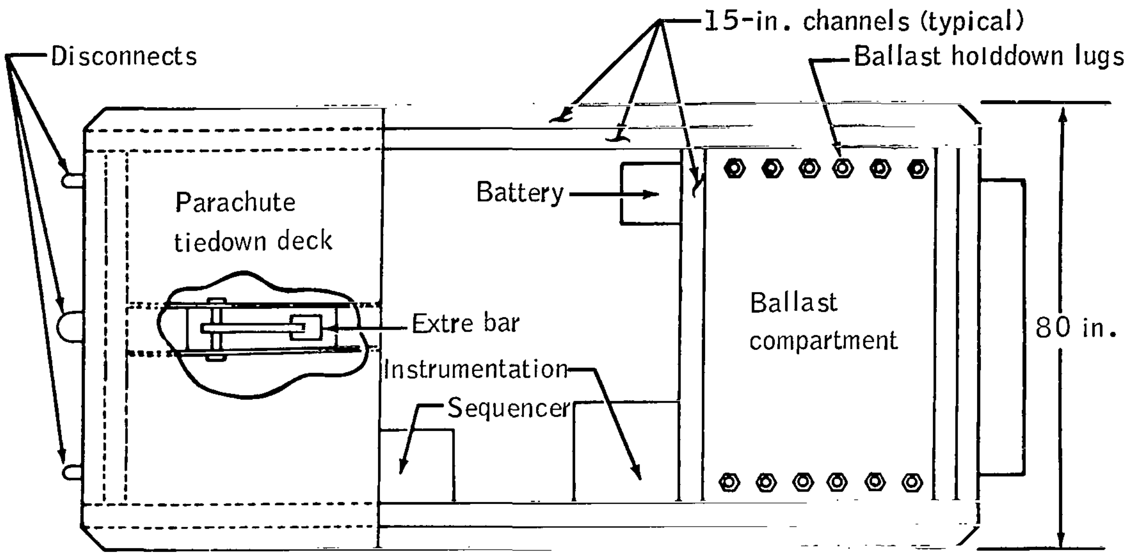
TEST PROCEDURE

The MSC Tests

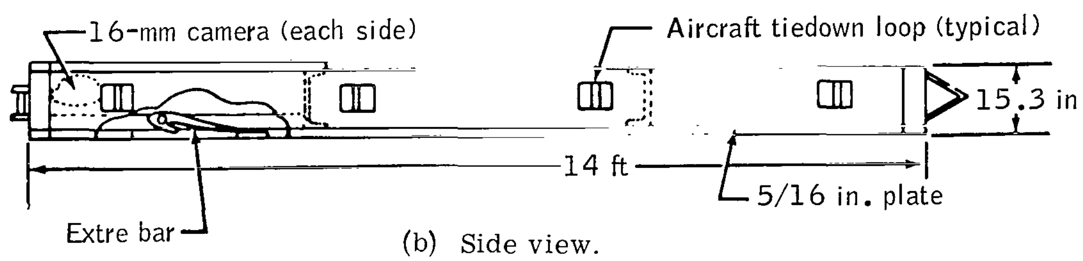
The test vehicle was extracted from a C-119 aircraft by a 22-foot ringslot parachute permanently reefed to an 18.8-foot diameter (fig. C-3). As the forward end of the test vehicle passed over the rear edge of the aircraft, the extre bar released and transferred the extraction force to the outside extraction parachute disconnects (on the front end of the test vehicle). After a short free fall (5 seconds), the extraction parachute disconnected from the test vehicle and deployed the main parachute. A 10-foot-diameter ringslot pilot parachute was used to stabilize the apex of the main parachute during the initial filling process. The pilot parachute, packed in the bottom of the main parachute deployment bag, was deployed at the time of main parachute line stretch.

The El Centro Tests

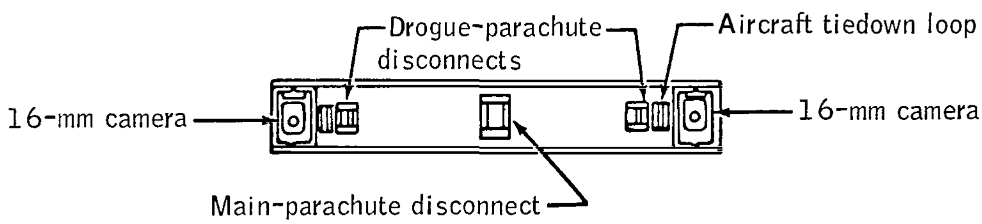
The first five El Centro tests were conducted with the C-130 aircraft and deployment system as shown in figure C-4. The platform and cradle (with weight bomb attached) were extracted from the C-130 with a 15-foot-diameter ringslot parachute permanently reefed to a 12-foot diameter. Immediately following extraction, a 6-foot, ribless-guide-surface pilot parachute was deployed by means of a static line attached to the aircraft. The pilot parachute severed the tiedown straps holding the weight bomb to the cradle and deployed the 64-foot flat, circular platform recovery parachute. A static line between the cradle and the weight bomb initiated deployment of the Century series ringsail parachute system. Several schemes were developed for deploying the Century series ringsail parachute following separation of the weight bomb from the cradle (figs. B-4 and B-5). The primary difference between deployment methods was the pilot parachute geometry and the bridle arrangement. Deployment of the Century series ringsail parachute was far simpler on tests 6 to 8. During these tests, the extraction system previously used was abandoned. The weight bomb was loaded directly into the drop-aircraft bomb bay (B-66 for tests 6 and 7; B-52 for test 8). Following release from the aircraft, a static line between the airplane and the weight bomb deployed the pilot parachute, which in turn deployed the Century series ringsail parachute.



(a) Top view.



(b) Side view.



(c) Front view.

Figure C-1. - Test vehicle, in-house tests 124.5-foot-D_o ringsail parachute.

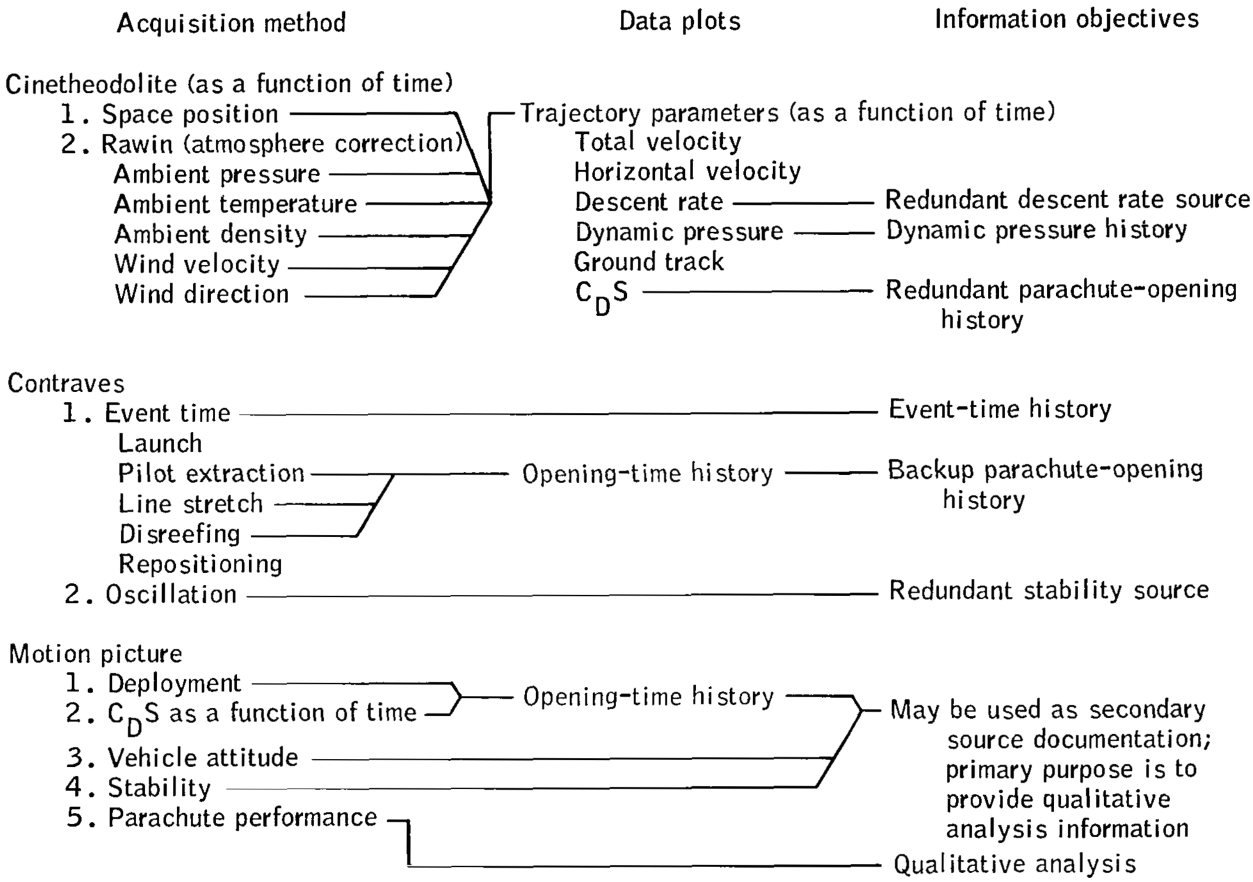


Figure C-2. - Data flow diagram, El Centro, California, facility.

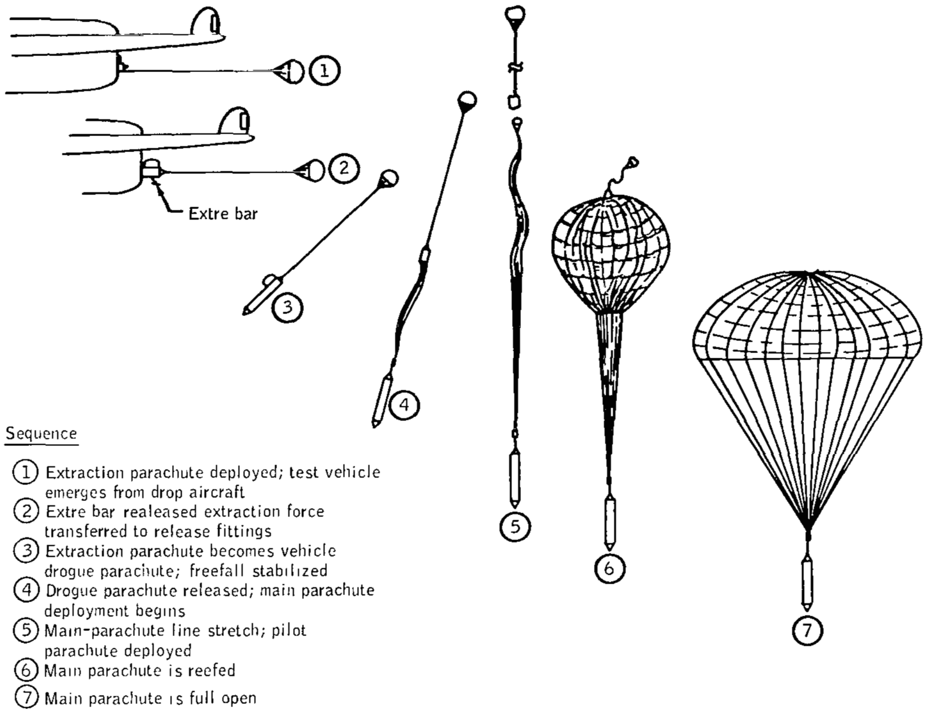


Figure C-3. - Typical sequence of events.

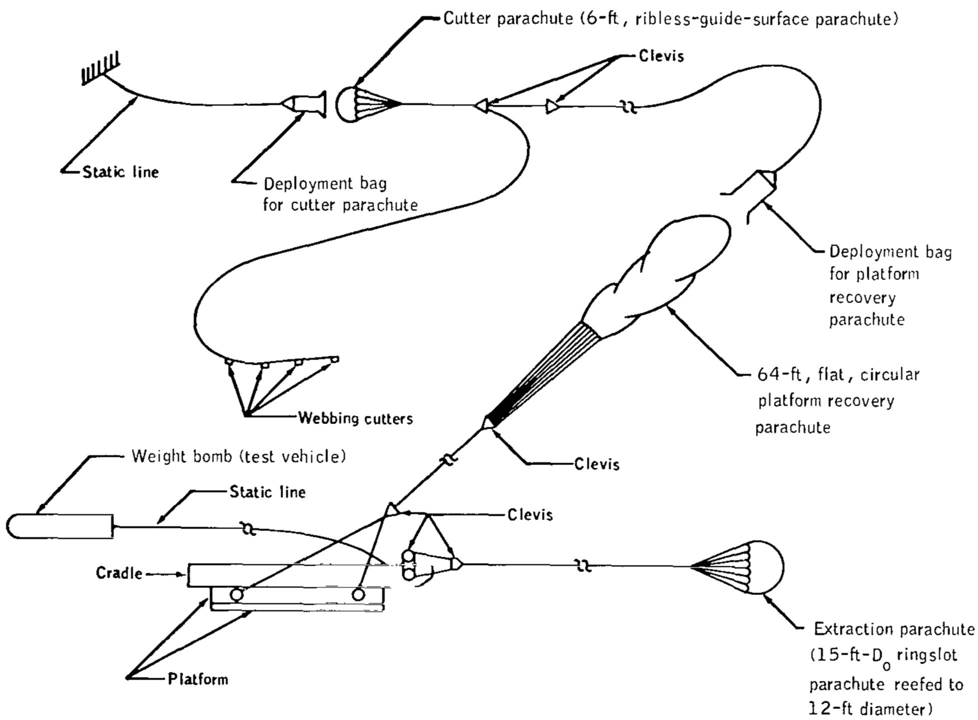


Figure C-4. - The C-130 aircraft deployment system.

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